Bench-Scale Assessment of Treatibility of Delta Waters

By

•Coagulation

•Membranes

Shahnawaz Sinha, Jinsik Sohn, Jaeweon Cho and Gary Amy

University of Colorado-Boulder

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Chapter 5

5.1 Treatment of Delta Island Drainage

The Municipal Water Quality Investigations (MWQI) Program is conducting a project to examine the feasibility of treating agricultural drainage into the Delta to remove total organic carbon (TOC), a measure of natural organic matter (NOM). Studies conducted on the Delta by Department of Water Resources (DWR) and others have found that drainage flows from approximately 260 agricultural drains discharging into the Delta represent the greatest individual source of TOC loading to the Delta. These agricultural discharges contribute high TOC loading due to the high organic content of the Delta peat soil.

Water retailers who are supplied by the Delta are concerned about the relatively high TOC levels that occur in Delta water. Higher TOC levels make it more difficult to treat the water because of the potential for higher disinfection-by-product (DBP) concentrations. Some retailers have already made treatment facility modifications to control DBP formation and others are preparing for the operational and physical changes they will need to comply with Phase I of the Disinfectant/Disinfection-by-products (D/DBP) rule and the Enhanced Surface Water Treatment Rule (ESWTR). Phase II of the D/DBP Rule will likely contain even more stringent DBP limits and compliance requirements than Phase I which will further challenge water retailers.

The cost to Delta water retailers to comply with the D/DBP and ESWTR will be significant. This fact has led to the consideration of alternatives for minimizing TOC and other DBP precursor

loadings to Delta water. The MWQI Workplan Subcommittee developed the study plan for this project to evaluate applying source control within the Delta island system to minimize the TOC loading from these islands.

5.2 Project Scope

The overall goal was to investigate various treatment methods that were carefully examined and evaluated for the most effective process to remove organics and minimize DBP (Disinfection-by-product) formation.

5.3 Sampling Plan

Samples were collected from two location within the Delta, these location are as follows:

Delta Sampling Locations:

1. Twitchell Island   -representing high peat soil drainage

2. Bacon Island   -representing medium peat soil drainage

These samples were collected during a severe flooding period (samples collected January 30th, 1997) and during a relatively dry winter period (March 12th, 1997). Thirty gallons of each water sample was shipped to CU-Boulder for bench-scale testing. These sample collected are designated

as *run-off* (to represent the severe flooding period) and *baseline* (for the dry winter period condition) water throughout this report.

5.4 Raw Water Quality

The samples received at the CU-Boulder environmental engineering laboratory were analyzed for total organic carbon (TOC), dissolved organic carbon (DOC), UV absorbance (UVA_{254}), pH, alkalinity, turbidity, color and conductivity. Table 5-1 shows the raw water quality for these two samples, in run-off and baseline events. Samples collected from Twitchell Island, which is of a higher peat content, exhibited a higher TOC, DOC, UVA_{254} and color for both events than the Bacon Island water. The specific UVA (SUVA) the ratio of UVA_{254} to DOC indicates a high aromatic content for both of these drainage waters.

The flooding significantly changed the raw water quality for the Delta water, causing higher than normal organic carbon levels. The raw water quality presented Table 5-1 shows water quality changed drastically from run-off to baseline conditions. Figure 5-1 shows the percent changes in the raw water quality between these two events and illustrates that organic carbon content for both Bacon and Twitchell in the run-off event increased fifty percent or more than the normal baseline conditions. This increase in TOC, DOC and UVA_{254} for both Bacon and Twitchell is due to the flooding and leaching of the high peat soil. However, other parameters such as turbidity and alkalinity decreased. These changes in alkalinity are more significant for the Bacon Island water than for Twitchell Island water.

Figures 5-2 and 5-3 depict the acid titration profiles for Bacon and Twitchell Island waters, respectively plotted as the amount of acid added (meq/L) vs. pH. Alkalinity imparts water its natural buffering capacity and can also be important from a treatment (i.e. in coagulation) point of view. The titration profile for Bacon Island (Figure 5-2) changed from run-off to the baseline condition, whereas for Twitchell Island, the profile (Figure 5-3) remained unchanged. Similarly, other titration profiles were developed for alum and iron (Figure 5-4 to 5-7) for these waters. These figures similarly show more changes in titration profiles for Bacon Island than Twitchell Island. All of these titration curves were used in the coagulation experiments to determine the amount of acid and/or coagulant required attaining a targeted pH. Waters of such a high TOC content are a challenge; this study undertaken by CU was to evaluate effective ways of treating these waters.

5.5 Experimental Plan

The following two types of treatment methods were considered in bench-scale testing for TOC removal effectiveness and to generate data on operational parameters:

1. Coagulation- enhanced and optimized coagulation using aluminum sulfate (alum, $Al_2SO_4 \cdot 14H_2O$) and ferric chloride (Iron, $FeCl_3 \cdot 6H_2O$); all doses reported herein correspond to mg/L as $Al_2SO_4 \cdot 14H_2O$ or $FeCl_3 \cdot 6H_2O$

2. Membrane treatment- nanofiltration and ultrafiltration membranes

5.5.1 Coagulation

Both optimized and enhanced coagulation (defined later) were examined and compared in this study. From these evaluations, the most effective and suitable coagulation method can be selected. Both alum and iron were also tested for their effectiveness in organic removal.

Enhanced coagulation, a method that enhances precursor removal by increasing the coagulant dosages, without independent pH adjustment, was evaluated for its effectiveness in removing organics. The organic removal criterion is based on raw water TOC and alkalinity. Table 5-2 shows the (3x3 matrix) TOC removal criteria for Step-1 of the Enhanced Coagulation Rule. Based on the alkalinity and raw water organic carbon content, both Bacon and Twitchell are required to remove forty percent (40%) or more of the organic carbon. The Step-2 requirements (Table 5-3) is the alternative performance criterion designed for those waters which will not be able to fulfill Step-1 of Enhanced Coagulation requirement. However, if the Delta waters are able to fulfill Step-1 of Enhanced Coagulation requirements, the residual TOC may still be high, producing significant amounts of DBPs, and unable to fulfill the Stage-1 of the D/DBP (Disinfection/Disinfection-by-product) Rule. To further reduce the organic carbon, significantly higher coagulant dosages may be required which may not be economical. Therefore, an alternative to the enhanced coagulation approach was needed for evaluation. Optimized coagulation, an approach in which, both pH level and coagulant dose are optimized, can maximize TOC removal, while reducing coagulant dosages, sludge production, and treatment cost. Herein, both enhanced and optimized coagulation was evaluated.

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5.5.1.1 Jar Tests for Enhanced and Optimized coagulation

Both enhanced and optimized coagulation were evaluated using jar tests, with 1-liter square jars were used in a 6-jar gang stirrer. Each jar was filled with 500 ml of sample water. The initial mixing speed for chemical addition and the 2-minute rapid mix was 100 revolutions per minute (rpm). For flocculation, the mixing speed was stepped down to 60 rpm, 40 rpm, and 20 rpm for 10 minutes each. The floc was allowed to settle for 30 minutes prior to sampling.

The settled water produced from the jar testing was analyzed for DOC, UVA_{254}, turbidity, color and zeta potential. DOC removals were determined instead of TOC removals. This is based on the fact that nearly all of the TOC is dissolved (94 percent for Twitchell Island and 92 percent for Bacon Island), and the assumption that the coagulation simulated in jar testing would remove all of the particulate organic carbon. Therefore, although DOC removals are reported, it can be assumed that the corresponding TOC removals would be almost identical.

5.5.1.2 Enhanced Coagulation

The Enhanced Coagulation Rule, along with its Step-1 and Step-2 criteria, applies to treatment plants providing drinking water to consumers. This is not the case for potential treatment plants in the Delta. Nevertheless, it represents a good framework for designing and interpreting jar test experiments.

Enhanced coagulation was determined by performing a series of jar-test from low to high dosage. Coagulant dosages that were employed to evaluate enhanced coagulation are shown in Table 5-4. In Step-1 of enhanced coagulation, only coagulant is added with no supplementary acid addition, with resultant dose-response curves. A typical dose-response curve shows a decline followed by flattening or a rise in settled water DOC levels, and a matching zeta potential curve that indicates destabilized floc particles (zeta potential near zero) matching the higher dose removals. When the end of the dose-response curve becomes relatively flat, showing little change in DOC removal with an increase in coagulant dose, this is considered to be the point of diminishing return (PODR).

5.5.1.3 Optimized Coagulation:

There are several steps (shown in Figure 5-8) that need to be followed in order to determine optimized coagulation. Jar test involved examining ranges of coagulant dose as shown in Table 5-5 and 5-6. The main objective was to determine a dose and an associated pH level that would be provide maximum DOC removal. Optimized coagulation was achieved in the following three steps.

Step-1 Determining Preliminary Coagulant Dose

The first step in determining the optimized coagulation condition is to determine a preliminary coagulant dose. This is determined by utilizing the enhanced coagulation dose response curve. From the dose response curve, a dose is selected that provide moderately effective DOC removal.

An intermediate dose is selected so that in Step-2 (pH screening), a more pronounced response to changes in pH levels is expected; i.e., the coagulant dose effects do not mask the effects of the pH adjustments. Measurements included DOC, UVA_{254}, turbidity, and zeta potential.

Step-2 Determining Optimum pH

Next, a series of jar tests are performed at a constant coagulant dose as determined in Step-1, while the pH in each jar is varied in increments of 0.5 units from 3.5 to 7.0 for alum and from 3.0 to 7.0 for ferric chloride. The terminology used for pH conditions are of following (1) ambient pH -reflects condition before any chemical (acid or coagulant) addition; (2) initial pH -reflects conditions after acid or base addition but before any coagulant addition (equal to ambient pH if no acid/base addition); (3) target pH -reflects instantaneous pH at rapid mix when both acid and coagulant are present (coagulant added within a few seconds of acid addition); and (4) final pH - reflects the pH of the post-coagulant addition/flocculation period condition. The titration curves (Figure 5-2 to 5-7) developed for acid and coagulant are now used to estimate the exact amount of acid that needs to be added to attain the targeted pH. In most instances, the target and the final pH were found to be similar.

After completion of the jar tests, the supernatant from each jar was measured for DOC, UVA_{254}, color, conductivity, turbidity, and zeta potential. The optimum pH is then selected which is not primarily based on DOC removal.

Step-3 Determining Optimum Coagulant Dose

Using the optimum pH levels selected for each coagulant in Step-2, a series of coagulant doses were evaluated for TOC removal. After completion of the jar testing the supernatant from each jar was measured for DOC, UV_{254}, color, conductivity, turbidity, and zeta potential.

The data were evaluated by plotting DOC removal versus coagulant dose, with similar plots developed for UV_{254} removal and zeta potential. Zeta potential was evaluated to determine the stability of the floc particles, a value approaching zero being desirable. If the dose-response curve was not able to reach the PODR then additional coagulant doses were tested. Once the optimum dose is determined (at the optimum pH), a large volume of sample was generated at that optimum pH-dose and shipped to the DWR lab for further analysis.

5.5.2 Membranes

The Twitchell Island run-off sample, which represented the highest TOC concentration, was chosen for the membrane testing. Various membranes were evaluated for NOM (natural organic matter) removal. Different types of membranes, including one nanofiltration membrane [Polyamide-NF45 membrane of Molecular Weight Cut-off (MWCO) 400 Dalton by FILMTEC] and three ultrafiltration membranes (Cellulose-YM3 of MWCO 3K Dalton by Amicon; Polyamide-GM of MWCO 8K Dalton by Desal and PolyEther Sulfonate-PM10 of 10K Dalton by Amicon) were used to reject NOM with the raw and iron-coagulated supernatant waters. NOM characterizations, such as DOC, UVA_{254}, color, and THMFP as well as ammonia, were measured

for the samples of the raw Twitchell water (feed) and membrane permeates. Flux through the membranes was also monitored over time.

5.5.2.1 Membrane Testing Experiments Methods

A commercial bench scale cross-flow membrane cell was used to evaluate flat sheet specimens. The system is comprised of the membrane unit and the feed, permeate, recycle, and waste lines. The system accommodates a 30-cm^2 flat sheet specimen under feed flow conditions of approximately 100 to 1,000 mL/min. This system permits a simulation of tangential flow, which is similar to actual operating conditions. The cross flow velocity can be varied by feed flow. Clean water was filtered through the flat sheet membrane until approximately constant flux was obtained, then Twitchell water was filtered. The permeate flow, UVA$_{254}$, and DOC of the permeate were measured over time. The SUVA of the permeate was compared with that of the feed sample to provide a measure of the removal of the aromatic component of NOM. Fluorescence intensity (370 nm excitation and 460 nm emission) was measured for the raw and membrane permeate. High Pressure Size Exclusion Chromatography (SEC) was used for determining the molecular weight (MW) distribution of NOM with a Waters® Protein-Pak column and a SPD-6A UV spectrophotometric detector. Eluent for the SEC was comprised of Milli-Q water buffered with phosphate (pH 6.8) and NaCl to increase ionic strength to 0.1 M. The membrane samples were chlorinated with NaOCl and incubated under dark condition for 72 hours; following quenching, MtBE (methyl tert-butyl ether) was used to extract THMs prior to GC/ECD analysis.

5.6 Results

The results of bench-scale testing for agricultural drain samples collected from Bacon Island and Twitchell Island during *run-off* (period of extreme flooding) and *baseline* (dry winter period) conditions in the Delta are presented below. As explained earlier, the bench-scale testing of these agricultural drainage samples included jar testing to test alum and ferric chloride coagulation and flat-sheet membrane testing to evaluate the performance of ultrafiltration and nanofiltration membranes.

5.6.1 Results of Enhanced Coagulation

Bacon Island Table 5-7 shows the enhanced coagulation results for Bacon Island during both events. Results show that alum was effective in treating this water during both events. Figure 5-9 shows the dose response curves for both events; PODR is reached at a dose of 125 mg/L where the DOC and UVA profiles flatten out. This dose may be selected as an effective alum-dose for treating this water for both events; nearly 60 percent of the DOC could be removed. Residual metal concentration (Al^{+3}) was also measured for the baseline condition, showing that the residual metal concentration is at a minimum at this dosage. This indicates that the amount of coagulant that had been added had effectively complexed with the NOM present and the residual or free metal present in the water is at its minimum. Thus for Bacon Island, 125 mg/L may be selected as the effective dose for treating this water before restabilization occurs.

Results for enhanced coagulation by iron are shown in Table 5-8 (jar tests experiments were performed only for the baseline conditions). The dose response curves (shown in Figure 5-12) reached the PODR at a dose of 125 mg/L. Based on the settled water quality, 125 mg/L may be selected as the enhanced coagulation dosage for treating this water. The free metal (Fe^{+3}) present in the water was also at its minimum, indicating effective coagulation. At this dosage, 67 percent of the DOC could be removed, and the floc characteristics were stable.

Twitchell Island Table 5-9 shows the enhanced coagulation results for the Twitchell Island water with alum treatment. Enhanced alum was effective in treating this water for both of the events. Figure 5-15 shows the dose response curves; the PODR for both events was nearly reached at a very high dosage of 250 mg/L. This high dose was found to be effective in reducing the organic content by more than 65 percent for the run-off water and 71 percent for the baseline water; however, restabilization/charge reversal occurred for both the events. The residual free metal (Al^{+3}) present measured for the baseline condition is at its minimum. Based on the settled water quality, a dosage of 225 to 250 mg/L would be selected as the enhanced coagulant dosage for effectively treating this water.

Iron was also used to treat this water; Table 5-10 shows the enhanced iron-coagulation results for Twitchell Island water. The dose response curve is plotted in Figure 5-18; this figure shows that the curve approaches but never reaches the PODR even at a high dose of 250 mg/L. At this dosage, 76 percent and 84 percent of the DOC could be removed for the run-off and baseline conditions, respectively. Based on settled water quality, an iron-dose of 250 mg/L may be selected as the effective dose for the run-off water. However a smaller dose may be selected for

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the baseline water, as significant charge reversal occurred. A dosage of about 125 mg/L may be selected as the effective dose for the baseline waters; at this dose the residual metal concentration is at its minimum.

The results of the enhanced coagulation tests indicate that this process could remove significant amounts of the organic carbon. However, large doses of metal coagulant would be required, indicating high chemical and sludge processing costs. Thus, optimized coagulation was evaluated to define its effectiveness and dose requirements compared to enhanced coagulation.

5.6.2 Results of Optimized Coagulation

<u>Bacon Island</u> The objective of the first step of the alum-optimized coagulation protocol is to evaluate a preliminary dose that would provide moderate but still effective DOC removal. The preliminary dose was selected by utilizing the dose response curve for enhanced coagulation (Figure 5-9 and Table 5-7). This figure shows that a dose of 25 mg/L can be selected as the preliminary dose for the run-off water and 50 mg/L dose for the baseline water. Lower dosages were selected for the run-off condition over the baseline condition, as less alum were required to show changes in DOC.

In the second step of the alum-optimized coagulation procedure, the dose is kept constant (at the preliminary dose determined from Step-1 of optimized coagulation) but the pH is varied by adding varying amounts of acid or base (from the titration curves of acid and coagulants) so that the targeted pH could be achieved. The pH was scanned from 3.5 to 6.5 to determine the pH that

would be optimum for the DOC removal. **Figure 5-10** shows the pH scan with alum for the run-off (at a constant dose of 25 mg/L) and baseline (at a constant dose of 50 mg/L) conditions. Table 5-11 shows the alum-pH scan results for the Bacon Island water. For both events, a pH of 4.5 was found to be the optimum alum-pH.

Next, in the third step of the alum-optimized coagulation protocol, a dose scan at the optimum pH (pH 4.5) was performed to evaluate a dose that would be most effective in organics removal. Figure 5-11 shows the dose response curves; for both events, a 100 mg/L dose was selected to be the effective for both the Bacon Island run-off and baseline waters. Table 5-15 shows other measured parameters for this assessment of alum-optimized coagulation. At the optimized dose, 48 and 74 percent of the DOC was removed for the run-off and baseline waters, respectively, and zeta potentials indicates that restabilization had not yet occurred. Residual metal concentration was present at its minimum. The optimum dose at the optimum pH (100 mg/L at pH 4.5) was used to generate large volume of treated water that was shipped to the DWR lab for further analysis (Table 5-19).

The first step of the iron-optimized coagulation testing involved examination of the dose response curve from the iron-enhanced coagulation (Table 5-8). Iron-enhanced coagulation was performed only for the baseline water. A dose of 25 mg/L was selected for the run-off sample and 75 mg/L was chosen for the baseline condition based on the preliminary dosages shown in Figure 5-12.

In the second step, optimized pH was determined. Figure 5-13 shows the iron-pH scan for the run-off (evaluated at constant dose of 25 mg/L) and baseline (evaluated at constant dose of 75

mg/L) conditions. Table 5-12 shows other measured parameters for iron-pH scan. The optimum pH was selected initially for the run-off sample as pH 4.6, and for the baseline sample as pH 3.7. However, for the run-off water, a pH near 3.5 is near the optimum pH (Figure 5-13). Thus, for both conditions, pH ~ 3.7 was taken as the optimum-iron pH for the Bacon Island water.

In the third step of the iron-optimized coagulation protocol, the optimum dose was determined (Figure 5-14). Both events for Bacon Island were evaluated at pH 3.7 (results are shown in Table 5-16). A dose of 85 mg/L was selected for the run-off sample, which is between 75 mg/L (where no restabilization occurred) and 95 mg/L (where stabilization had occurred). A dose of 50 mg/L was chosen as the optimum dose for the baseline water, which is higher than 35 mg/L and less than 55 mg/L, based on the zeta potential. The selected optimum dose could remove 55 percent and 75 percent of the DOC for the run-off and baseline conditions, respectively.

Based upon these results, 100 mg/l at a target pH of 4.5 was selected to be an optimum alum condition for the Bacon Island waters derived from both events. For ferric chloride, doses of 85 mg/L and 50 mg/L, both at a target of pH 3.5 were chosen for both the run-off and baseline waters, respectively. Like alum, large samples were generated under optimum iron conditions for further analysis (Table 5-19).

Twitchell Island The preliminary dose was evaluated by utilizing the dose response curve of the alum-enhanced coagulation test (Figure 5-15). A dose of 75 mg/L was selected as the preliminary dose for the run-off water, and 50 mg/L was selected as the optimum dose for the baseline water.

Table 5-9 shows the alum-enhanced coagulation results, wherein the doses selected were moderate but still effective in DOC removal.

In the second step of the alum-optimized coagulation testing, the dose was kept constant while the pH was varied by adding varying amounts of acid or base (from the titration curves of acid and coagulants). The pH was varied from 3.0 to 6.5 to determine the effective pH that would be optimum for DOC removal. Figure 5-16 shows the pH scan with alum for the run-off (at a constant dose of 75 mg/L) and baseline (at a constant dose of 50 mg/L) conditions. Table 5-13 shows other measured parameter for the alum-pH scan for Twitchell Island water. For both events, a pH of ~4.5 was found to be the optimum alum-pH for this water.

Next, in the third step of the alum-optimized coagulation procedure, the optimum dose needed to be determined. A dose scan at the optimum pH (pH ~4.5) was performed that would be effective in organic removal. Figure 5-17 shows the dose response curves and, for the both events, 100 mg/L of alum was selected to be the effective dose for treating this waters. Table 5-17 summarizes other measured parameters for this alum-optimized coagulation. The selected optimum dose of 100 mg/L was found to be effective in removing 44 and 67 percent of the DOC. Zeta potential indicates that restabilization had not yet occurred. Residual metal concentration was present at its minimum. This dosage and pH were later selected as the optimum condition to generate a large volume of treated water for further analysis (Table 5-18).

In the iron-optimized coagulation testing, the preliminary dose was first determined for iron by utilizing the dose response curve for the iron-enhanced coagulation experiment (Table 5-10). For

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both events (Figure 5-18), a dose of 75 mg/L was chosen as the preliminary dose for Step-1 of iron-optimized coagulation.

Second, iron-optimized coagulation was evaluated to define the optimum pH. Figure 5-19 shows the iron-pH scan for the run-off (evaluated at a constant dose of 75 mg/L) and baseline (evaluated at a constant dose of 75 mg/L). Other measured parameters for the iron-pH scan are shown in Table 5-14. The optimum pH was selected to be ~3.5 for both the run-off and baseline waters, respectively.

Third, iron-optimized coagulation for both the run-off and baseline waters was evaluated at pH 3.7 (results shown in Table 5-18). A dose of 95 mg/L was selected for the run-off water, whereas a dose of 85 mg/L was chosen as the optimum dose for the baseline water. The selected dose for the run-off water was able to remove 69 percent and 74 percent of the DOC from the run-off and baseline waters, respectively

Based on these results, 100 mg/L at a pH of 4.5 was selected as the alum-optimized coagulation condition, for both events of Twitchell water. The optimized coagulation doses for iron treatment were 95 mg/l and 85 mg/L, both at target pH of 3.5, for run-off and baseline waters, respectively. Table 5-19 shows the results of the Twitchell Island water by optimized alum and iron treatment. Under these conditions, large volumes of samples were generated and shipped to the DWR lab.

5.6.3 Enhanced Coagulation Compared to Optimized Coagulation

To compare the impact that pH adjustment had on required coagulant dose and DOC removal, the optimized coagulation results for drainage samples were compared to the enhanced coagulation. Figures 5-21 and 5-22 shows the enhanced vs. optimized coagulation with alum and iron for the Bacon Island water, respectively. These figures shows that optimized coagulation with either alum or iron are generally more effective than enhanced coagulation in removing organic carbon from the Bacon Island waters.

Similar figures (Figure 5-23 and Figure 5-24) for Twitchell Island indicates once again that optimized coagulation is more effective for both alum and iron treatment. Recall that enhanced coagulation involves controlling only coagulant dose to achieve the greatest DOC removal whereas optimized coagulation involves controlling coagulant dose as well as pH level to achieve the greatest DOC removal.

Figure 5-25 and 5-26 are bar graphs again to compares optimized coagulation with the enhanced coagulation (on equivalent dose basis) for the run-off and baseline conditions, respectively. In both events the optimized coagulation is found to be more effective over enhanced coagulation. A significant reduction in coagulant dosages could be achieved by optimizing the coagulation process, although a rigorous cost analysis should take into account the cost of acid addition.

5.6.3.1 Alum vs. Iron coagulation:

From the above discussion it is clear that optimized coagulation will be more effective in treating the high TOC Delta water. The next task was to evaluate which of the coagulants would be more effective. Alum and iron were compared for their effectiveness in both the enhanced and optimized coagulation processes. Figure 5-27 and 5-28 shows results for alum and iron in enhanced and optimized coagulation for Bacon Island waters, respectively. The results suggest that alum was more or equally effective as iron in enhanced coagulation (Figure 5-27); whereas, iron was more effective in optimized coagulation (Figure 5-28).

Similar figures were plotted for Twitchell Island water where alum was compared with iron in enhanced and optimized coagulation. Figure 5-29 shows that alum was equal or slightly better than iron in enhanced coagulation, whereas Figure 5-30 indicates that iron was a better coagulant in optimized coagulation.

A stability diagram (based on final pH and dose) was used to determine the coagulation mechanism of enhanced (pH is not adjusted, so initial pH is equal to ambient pH) and optimized coagulation (pH is depressed/adjusted, so initial pH is lower than ambient pH). Figure 5-31 shows alum-enhanced coagulation for both Bacon and Twitchell lies within the sweep floc region of the diagram, whereas alum-optimized coagulation lies within the charge neutralization zones. Figure 5-32 shows the iron stability diagram; iron-enhanced coagulation once again lies within the sweep region of the stability diagram, whereas iron-optimized lies within the charge neutralization zone.

The results support the premise that optimized coagulation is more effective than enhanced coagulation in organics removal. Moreover iron which was found to be more effective than alum within this charge-neutralization zone (optimized coagulation), whereas alum was more effective than iron within the sweep coagulation zone (enhanced coagulation). These results suggest that the mechanism by which alum and iron interact with organic matter may be different. Alum may be more effective in the sweep coagulation zone by forming hydroxide surfaces, whereas iron may be more effective in charge-neutralization, where, at low pH, its hydrolysis species are more effective. Therefore, for the Delta waters, if optimized coagulation is chosen as the approach for reducing organic carbon, the appropriate choice would be iron over alum as a coagulant.

5.6.3.2 Highest DOC Removal

Based upon the results generated from the jar testing, effective DOC removal could be achieved by coagulation. Figures 5-33 and 5-34 show percent removals of various parameters for Bacon and Twitchell Island waters under alum and iron optimized treatment for the two events. In all cases, iron was found to be very effective in organic carbon (i.e. DOC) removal. Iron-optimized coagulation was found to be very effective in DOC reduction. For Bacon Island, dose of 85 mg/L and 50 mg/L under iron-optimized coagulation removed 60 and 70 percent of the DOC from run-off and baseline waters, respectively. Moreover, iron significantly reduced other important parameters. For Twitchell Island, a dose of 95 mg/L and 85 mg/L under iron-optimized coagulation removed nearly 70 percent of the DOC. However, the high iron dose and low final pH represent potential obstacles, which should be carefully considered in further evaluation of this treatment alternative.

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5.6.4 Results of Membrane Testing

Figures 5-35 to 5-38 represents flux decline curves of various membranes with the Twitchell raw water; each of these curves shows initial filtration with de-ionized water followed by Delta sample filtration. There was no significant flux decline except for the PM10 membrane, which had a high permeability, compared to the other membranes. Figures 5-37 and 5-38 exhibit calcium effects on flux decline and NOM rejection for the GM membrane and raw Twitchell water. Calcium (Ca^{+2}) complexes with NOM, affecting both its charge and size. There was little difference in flux decline (slightly more flux decline with the Twitchell water spiked with 4 mM Ca), while the NOM rejections based on DOC and UVA were decreased by the addition of calcium, representing reduced charge-repulsion effects on NOM rejection. For the iron-coagulated supernatant water, both NF45 and GM membranes did not show any significant flux declines (see Figures 5-39 and 5-40).

Figure 5-41 shows the water quality comparisons between the raw Twitchell and membrane permeate waters. Even UF membranes including YM3, GM, and PM10 could provide NOM rejection performances ranging from 40% to 60%, because of the large molecular weight distribution and relatively high hydrophobicity based on SUVA of the raw the Twitchell water (see Figure 5-42). The NF45 resulted in nearly complete organic rejection for raw Twitchell water. The THMFP and chloral hydrate formation potential (CHFP) removals for the Twitchell water were similar to the UVA removals (see Figure 5-42). Various conditions with Twitchell water were tested with the GM membrane to determine the effects of pH, ionic strength, and calcium on NOM removal (see Figure 5-43). The NOM removal was slightly reduced at lowered

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pH due to the lowered charge density of NOM. The NOM removal was somewhat reduced in the presence of calcium, representing the importance of the charge repulsion between NOM and the membrane surface. The MW distributions of the raw Twichell water and GM membrane permeate are shown in Figure 5-44.

Figure 5-45 exhibits the NOM rejections of iron-coagulated supernatant water by the GM and NF45 membranes, respectively. The MW distributions of the raw Twitchell water, iron-coagulated supernatant water, and the GM membrane permeate of the iron-coagulated supernatant water are shown in Figure. 5-46.

5.6.5 Modeling Effort

Finally, the objective was to develop a mathematical model for optimized coagulation that would be applicable within the Delta for predicting the treated water organic carbon content (DOC). This model could be used to estimate the coagulant dose that would be necessary to attain a certain water quality. Models were developed for optimized-alum and optimized-iron coagulation. These models were developed to be applicable to accept wide variation of raw water quality. Variation in raw water quality can occur from location to location and from season to seasons.

Optimized coagulation was found to be effective in organic carbon removal, however the removal is influenced by raw-water characteristics such as DOC, pH and alkalinity. Furthermore, the coagulant type, coagulant dosage, and the amount of acid or base applied all have impacts on DOC removal. In optimized coagulation, pH condition were adjusted by adding acid or base,

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hence raw water DOC, coagulant dosage and final pH were considered as independent variables. Three general modeling approaches were used in the development of the empirical models for treated DOC concentrations and % DOC removals.

1.   Multiple Linear Regression Model.

2   Multiple Semi-Log Regression Model with logarithmic transformation of only independent variables.

3.   Multiple Log-Log Regression Model with logarithmic transformation of both dependent and independent variables.

These modeling efforts were done using the STATISTICA, a statistical package on an IBM personal computer.

DOC models and % DOC removal models were developed with data derived from alum coagulation (n = 84) and iron coagulation (n = 77). The models were generated at 20 °C; hence they are not valid at other temperature. Other important boundary conditions are presented in Table 5-20. Statistical parameters included in the model are the number of case (n), the multiple coefficient of determination (r^2), and the F statistics. Each model was tested through an internal validation representing a data simulation with data actually used in model calibration. A perfect data simulation between predicted and measured values would be represented by a regression line with a slope of zero, an intercept of 1.0, and r^2 of 1.0.

A potential correlation of DOC removal and the ratio of dose/DOC were first examined. Figures 5-47 and 5-48 for alum-optimized and iron-optimized coagulation show good correlation ($r^2 =$ 0.91 for alum and 0.83 for iron) between DOC removal and dose/DOC ratio. Logarithm regressions showed better correlation than linear regressions for both alum coagulation and iron coagulation.

5.6.5.1 DOC Models

Three types of models were developed to evaluate the accuracy of prediction for the final DOC of coagulated waters. Table-5-21 shows three treated water DOC models for alum and iron coagulation: a multiple linear model, a semi-log model, and a log-log model. Based on the r^2 and F values, the log-log models for both alum coagulation and iron coagulation represent the best predictions.

5.6.5.2 DOC Removal Models

Table-5-22 shows three DOC removal models for alum coagulation and iron coagulation. Based on the r^2 and F values, the semi-log models for both alum coagulation and iron coagulation represent best predictions.

5.6.5.3 Internal Validation of Models

Even though final validation of any model should be accomplished with independent data, preliminary testing of a model against the data base used in calibration, hereafter referred to as "internal validation", can provide insight into model applicability and limitations. Two types of approaches to compare predicted values with measured values were taken.

The first approach to internal validation involved conducting a regression of predicted values of the parameter against measured values for each model, and developing a corresponding scatter diagram. According to this analysis, a perfect model would result in a r^2 value of 1.0 and yield a regression equation with an intercept of zero and slope of 1.0. These results are presented in Figures 5-49 to 5-52.

The second approach involves estimating an "index of agreement", I, as defined below:

I = [Predicted Value - Measured Value]/ [Measured Value]

A "criterion of agreement" for I is defined as follows:

$0.75 < I < 1.25$

Results of the index of agreement analysis of the DOC models for alum coagulation and iron coagulation are presented in Table 5-23. It can be seen that 77% of the predictions of final DOC

with alum coagulation fall within 25% of the measured values and 58% of the predictions of final

DOC for iron coagulation falls within 25% of measured values.

5.6.5.4 Model Simulation

An important attribute of these models is that they allow final DOC predictions of coagulation without performing all jar-tests. Figures 5-53 and 5-54 show simulation results based on a raw-water DOC of 20 mg/L for alum coagulation and iron coagulation, respectively. These simulations show iron to be more sensitive to pH (Figure 5-54) than alum (Figure 5-53).

These models were developed at 20°C and are not valid at other temperature. The other limitation of these models is that they need to be used within the defined boundary conditions. Because coagulant dosages and pH can be controlled, several matrices of dosage and final pH can be evaluated, and the optimization of cost and treatablity can be accessed. Moreover, this information can be used in designing pilot-scale experiments.

Table 5-1 : Raw Water Quality of Delta Waters

	Bacon		Twitchell	
	Run-off	Baseline	Run-off	Baseline
TOC (mg/L)	25.34	12.38	41.89	22.14
DOC (mg/L)	24.37	11.15	40.84	21.38
UVA_{254} (cm^{-1})	0.980	0.633	1.811	1.107
SUVA (mL/mg)	4.02	5.68	4.43	5.18
Turbidity (NTU)	19	25	15	22
Color (CU)	140	145	246	213
Conductivity (μS)	980	465	1047	883
pH	7.5	7.3	7.4	7.2
Alkalinity (mg/L as $CaCO_3$)	60	100.8	80	87

Table 5-2: Performance Criteria for Step-1 of Enhanced Coagulation

Source Water TOC (mg/L)	Source Water Alkalinity (mg/L as $CaCO_3$)		
	0-60	>60-120	>120
>2.0-4.0	40%	30%	20%
>4.0-8.0	45%	35%	25%
>8.0	50%	40%	30%

Table 5-3: Alternate Performance Criteria, Step-2 of Enhanced Coagulation

Step-2 of enhanced coagulation achieved at a slope = 0.03 (mg/L/mg/L)

TOC (mg/L)

Alum (or Ferric Salt Equivalent) Dose, mg/L

Maximum pH Levels:

Raw Water Alkalinity, (mg/L as $CaCO_3$)			
0-60	60-120	>120-240	>240
5.5	6.3	7.0	7.5
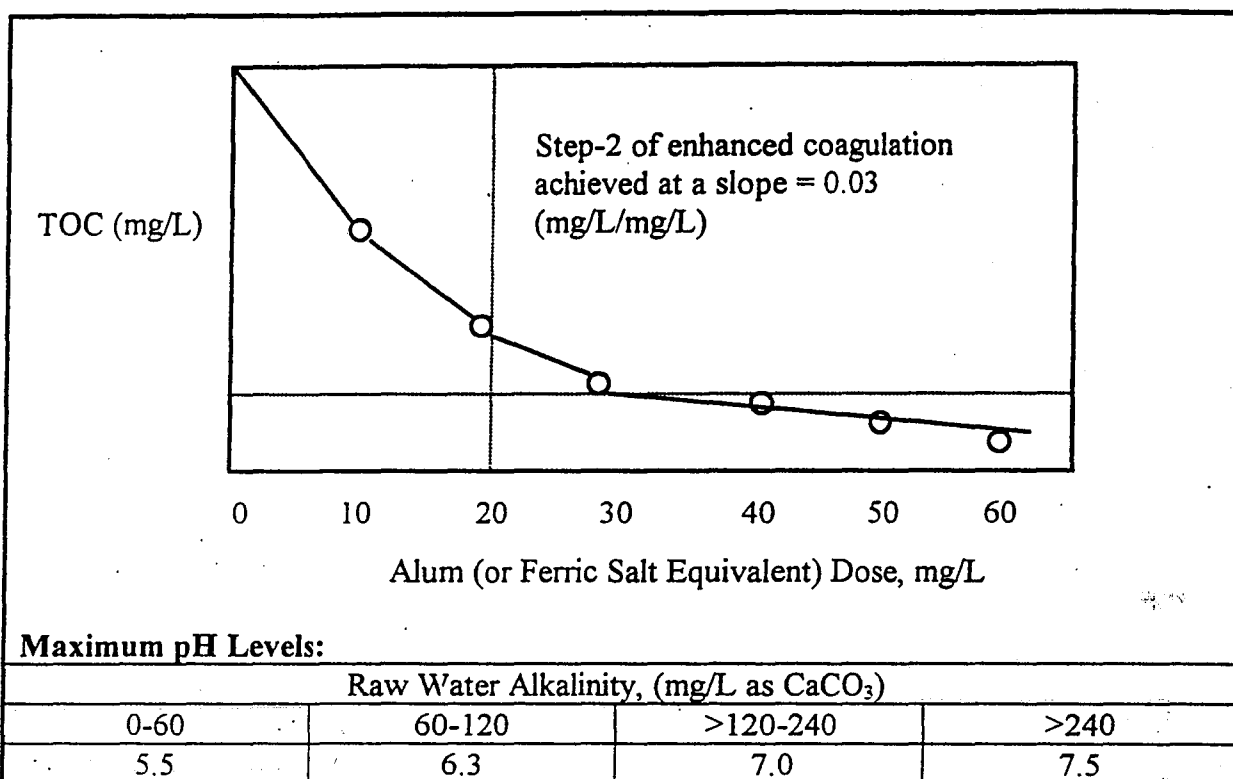
Table 5-4 Coagulant Doses Evaluated for Enhanced Coagulation of Run-off and Baseline Samples

Alum dose (mg/l)	10	25	50	75	125	250
Ferric chloride dose (mg/l)	10	25	50	75	125	250

Table 5-5 Coagulant Doses Evaluated for Optimized Coagulation of Run-off Samples

Alum dose (mg/l)	10	20	40	60	80	100
Ferric chloride dose (mg/l)	5	15	35	55	75	95

Table 5-6 Coagulant Doses Evaluated for Optimized Coagulation of Baseline Samples

Alum dose (mg/l)	10	20	40	60	80	100	125	150	200
Ferric chloride dose (mg/l)	5	15	35	55	75	95	120	150	200

Table 5-7 Alum-Enhanced Coagulation of Bacon Waters

Dose (mg/l)	Final pH	DOC (mg/l)	% DOC Removal	UV_{254} (cm^{-1})	SUVA (mL/mg)	Turb. (NTU)	Res. Al^{+3} (mg/L)	Zeta (mV)
Run-off								
10	6.74	22.38	8	0.958	4.28	13	N/A	-10.22
25	**6.45**	**22.28**	**9**	**0.908**	**4.08**	**12.5**	**N/A**	**-11.46**
50	6.24	18.84	23	0.674	3.58	7	N/A	-14.77
75	6.06	14.76	39	0.427	2.89	2.4	N/A	-20.43
125	5.12	10.16	58	0.240	2.36	3.2	N/A	-5.11
250	4.02	11.51	53	0.288	2.50	2.8	N/A	-1.66
Baseline								
10	6.95	11.14	0	0.630	5.66	10	0.49	-17.4
22.5	6.76	11.68	0	0.627	5.37	10	1.96	-10.49
50	**6.50**	**9.76**	**13**	**0.453**	**4.64**	**11**	**2.03**	**-19.05**
75	6.30	5.92	47	0.178	3.01	4	0.16	-17.40
125	5.99	4.46	60	0.111	2.49	5.5	0.09	-11.18
250	4.55	3.24	71	0.068	2.10	8	0.49	11.87

Table 5-8 Iron-Enhanced Coagulation of Bacon Waters

Dose (mg/l)	Final pH	DOC (mg/l)	% DOC Removal	UV_{254} (cm^{-1})	SUVA (mL/mg)	Turb. (NTU)	Res. Fe^{+3} (mg/L)	Zeta (mV)
Baseline								
10	7.04	9.86	12	0.752	7.63	11	2.95	-21.95
25	6.75	10.36	7	0.959	9.26	13	5.95	-17.12
50	6.50	10.55	5	1.192	11.30	14	9.82	-18.92
75	**6.27**	**7.55**	**32**	**0.693**	**9.18**	**9.5**	**4.95**	**-18.92**
125	5.96	3.73	67	0.104	2.79	0.22	0.02	-12.15
250	3.02	1.82	84	0.136	7.47	6.4	1.52	17.67

(Bold indicates coagulant dose chosen for the Step-1 of the optimized coagulation)

Table 5-9 Alum-Enhanced Coagulation of Twitchell Waters

Dose (mg/l)	Final pH	DOC (mg/l)	% DOC Removal	UV$_{254}$ (cm^{-1})	SUVA (mL/mg)	Turbidity (NTU)	Res. Al^{+3} (mg/L)	Zeta (mV)
Run-off								
10	6.63	36.42	10	1.787	4.91	7	N/A	-12.70
25	6.48	37.52	8	1.792	4.78	8	N/A	-12.98
50	6.30	37.18	9	1.784	4.80	11	N/A	-14.50
75	**6.09**	**35.24**	**13**	**1.693**	**4.80**	**20**	**N/A**	**-16.57**
125	5.62	19.49	52	0.618	3.17	8	N/A	-10.91
250	4.06	14.20	65	0.360	2.54	4	N/A	1.52
Baseline								
10	6.99	20.60	4	1.066	5.17	16	0.90	-18.09
25	6.77	20.14	6	1.046	5.19	16	1.86	-17.26
50	**6.56**	**19.21**	**10**	**0.892**	**4.64**	**18**	**3.60**	**-25.54**
75	6.32	14.56	32	0.542	3.72	6	1.25	-15.88
125	5.961	8.79	59	0.209	2.38	11	0.09	-15.88
250	4.36	6.18	71	0.134	2.17	40	2.97	6.77

Table 5-10 Iron-Enhanced Coagulation of Twitchell Waters

Dose (mg/l)	Final pH	DOC (mg/l)	% DOC Removal	UV$_{254}$ (cm^{-1})	SUVA (mL/mg)	Turbidity (NTU)	Res. Fe^{+3} (mg/L)	Zeta (mV)
Run-off								
10	6.58	35.92	12	1.932	5.38	7	N/A	-14.5
25	6.43	38.84	4	2.112	5.44	8	N/A	-22.23
50	5.95	34.28	16	2.383	6.95	12.5	N/A	-13.53
75	**5.64**	**37.88**	**7**	**2.489**	**6.57**	**16**	**N/A**	**-13.67**
125	4.60	15.39	62	0.438	2.85	4	N/A	-3.04
250	2.85	9.77	76	0.495	5.07	3.4	N/A	4.42
Baseline								
10	6.97	21.26	1	1.207	5.68	17	3.83	-16.29
25	6.75	21.15	1	1.407	6.65	18	6.62	-20.16
50	6.46	21.07	1	1.654	7.85	22	10.47	-18.36
75	**6.18**	**19.16**	**11**	**1.73**	**9.03**	**22**	**13.24**	**-20.57**
125	5.74	8.09	62	0.239	2.95	1.4	0.27	-15.46
250	2.89	3.46	84	0.303	8.76	1.9	4.41	18.64

(Bold indicates coagulant dose chosen for the Step-1 of the optimized coagulation)

Table 5-11 Alum-pH Scan of Bacon Waters

Dose (mg/l)	Acid (meq/L)	Final pH	DOC (mg/l)	% DOC Removal	UV$_{254}$ (cm^{-1})	SUVA (mL/mg)	Color (CU)	Cond. (uS)	Turb. (NTU)	Res. Al^{+3} (mg/L)	Zeta (mV)
Run-off											
25	1.17	3.64	24.16	1	0.918	3.80	103	1081	7.5	2.68	-9.8
25	1.00	4.14	23.67	3	0.801	3.38	81	1053	5.3	1.92	-21.95
25	0.92	4.36	23.03	5	0.766	3.33	73	1057	4	1.57	-5.94
25	**0.83**	**4.77**	**22.95**	**6**	**0.733**	**3.19**	**75**	**1048**	**7.2**	**0.39**	**-8.7**
25	0.68	5.26	24.06	1	0.879	3.65	112	1049	14	0.41	-14.64
25	0.34	5.90	25.40	0	0.926	3.65	133	1042	12	0.11	-9.53
Baseline											
50	1.64	4.34	5.15	54	0.151	2.93	20	N/A	2.4	0.85	-4.14
50	**1.54**	**4.69**	**4.41**	**60**	**0.116**	**2.63**	**15**	N/A	**1.9**	**0.06**	**-3.04**
50	1.41	5.09	4.64	58	0.117	2.52	13	N/A	3	0.04	-9.94
50	1.09	5.63	5.33	52	0.154	2.89	20	N/A	2.9	0.10	-1.66
50	0.56	6.14	6.50	42	0.229	3.52	34	N/A	3.2	0.36	-11.74
50	0.00	6.45	9.18	18	0.442	4.81	85	N/A	11	1.93	-13.81

(Bold indicates pH chosen for the Step-2 of the optimized coagulation)

Table 5-12 Iron-pH Scan of Bacon Waters

Dose (mg/l)	Acid (meq/L)	Final pH	DOC (mg/l)	% DOC Removal	UV_{254} (cm^{-1})	SUVA (mL/mg)	Color (CU)	Cond. (uS)	Turb. (NTU)	Res. Fe^{+3} (mg/L)	Zeta (mV)
Run-off											
25	1.05	3.41	24.16	1	0.931	3.85	N/A	N/A	14	N/A	N/A
25	0.98	3.82	26.22	0	1.125	4.29	N/A	N/A	16	N/A	N/A
25	0.90	4.19	27.02	0	1.206	4.46	N/A	N/A	16	N/A	N/A
25	**0.96**	**4.67**	**22.44**	**8**	**0.735**	**3.28**	N/A	N/A	**7**	**N/A**	N/A
25	0.86	4.89	21.87	10	0.719	3.29	N/A	N/A	10	N/A	N/A
25	0.77	5.26	23.03	5	0.849	3.69	N/A	N/A	17	N/A	N/A
25	0.66	5.62	24.25	0	0.904	3.73	N/A	N/A	19	N/A	N/A
25	0.43	6.05	22.03	10	0.857	3.89	N/A	N/A	18	N/A	N/A
25	0.30	6.28	23.56	3	0.914	3.88	N/A	N/A	17	N/A	N/A
25	0.00	6.56	25.73	+6	1.16	4.51	N/A	N/A	16	N/A	N/A
Baseline											
75	2.82	2.66	4.70	58	0.99	21.06	218	N/A	2.5	11.78	-1.38
75	1.59	3.25	2.73	76	0.133	4.87	26	N/A	0.7	1.17	-1.52
75	**1.44**	**3.71**	**2.32**	**79**	**0.063**	**2.72**	**10**	N/A	**0.4**	**0.14**	5.99
75	1.36	3.75	2.26	80	0.057	2.52	10	N/A	0.3	0.09	N/A
75	1.36	3.63	2.20	80	0.062	2.82	10	N/A	1.5	0.00	-7.59
75	1.22	4.58	2.88	74	0.056	1.94	10	N/A	1.4	0.02	-12.7
75	0.19	5.45	6.63	41	0.099	1.49	15	N/A	1.6	2.66	+0.69

(Bold indicates pH chosen for the Step-2 of the optimized coagulation)

Table 5-13 Alum-pH Scan of Twitchell Waters

Dose (mg/l)	Acid (meq/L)	Final pH	DOC (mg/l)	% DOC Removal	UV_{254} (cm^{-1})	SUVA (mL/mg)	Color (CU)	Cond. (uS)	Turb. (NTU)	Res. Al^{+3} (mg/L)	Zeta (mV)
Run-off											
75	1.88	2.94	38.88	5	1.749	4.50	N/A	N/A	5.3	7.22	N/A
75	1.09	3.75	39.59	3	1.554	3.93	N/A	N/A	6.2	6.91	N/A
75	0.83	4.22	34.42	16	1.197	3.48	N/A	N/A	5.4	5.02	N/A
75	0.71	4.40	30.52	25	0.916	3.00	N/A	N/A	5.8	3.21	N/A
75	**0.71**	**4.58**	**22.64**	**45**	**1.009**	**4.46**	N/A	N/A	**10**	-	N/A
75	0.60	4.68	26.18	36	0.859	3.28	N/A	N/A	7	1.95	N/A
75	0.60	4.95	26.64	35	1.023	3.84	N/A	N/A	14	-	N/A
75	0.47	5.41	27.24	33	1.472	5.40	N/A	N/A	27	-	N/A
75	0.43	5.25	30.52	25	1.273	3.87	N/A	N/A	23	3.02	N/A
75	0.13	6.02	32.90	19	1.742	5.29	N/A	N/A	20	-	N/A
75	0.0	6.48	36.62	10	1.759	4.80	N/A	N/A	15	-	N/A
75	0.0	6.70	37.54	8	1.768	4.71	N/A	N/A	13	-	N/A
Baseline											
50	1.50	4.18	16.65	22	0.612	3.68	63	929	1.4	3.22	-13.54
50	1.41	4.43	14.46	32	0.476	3.29	46	919	1.8	2.01	+0.69
50	**1.29**	**4.73**	**12.54**	**41**	**0.377**	**3.01**	**36**	**918**	**3.2**	**0.78**	**-9.66**
50	1.11	5.31	12.83	21	0.435	3.39	60	902	7.7	0.51	-14.91
50	0.69	5.87	16.93	21	0.817	4.83	161	899	20	3.75	-15.46
50	0.07	6.50	18.78	12	0.906	4.82	169	889	18	3.66	-18.09

(Bold indicates pH chosen for the Step-2 of the optimized coagulation)

Table 5-14 Iron-pH Scan of Twitchell Waters

Dose (mg/l)	Acid (meq/L)	Final pH	DOC (mg/l)	% DOC Removal	UV_{254} (cm^{-1})	SUVA (mL/mg)	Color (CU)	Cond. (uS)	Turb. (NTU)	Res. Fe^{+3} (mg/L)	Zeta (mV)
Run-off											
75	1.15	3.22	15.75	61	0.544	3.45	57	1223	3.2	2.34	+0.83
75	0.90	**3.49**	**15.30**	**63**	**0.452**	**2.95**	**49**	**1176**	**2.6**	**1.24**	-4.28
75	0.77	3.78	15.71	62	0.563	3.58	72	1150	7.7	1.32	-5.66
75	0.66	4.23	27.82	32	1.644	5.91	317	1128	23	6.50	-16.02
75	0.49	4.92	37.68	8	2.286	6.07	426	1136	21	9.98	-16.15
75	0.19	5.6	37.16	9	2.43	6.54	477	1117	18	11.44	-7.87
Baseline											
75	1.71	2.89	8.37	61	0.623	7.44	133	768	0.5	5.79	0
75	1.24	3.06	5.61	74	0.339	6.04	68	1043	0.5	3.12	-2.99
75	1.07	**3.45**	**5.08**	**76**	**0.142**	**2.80**	**18**	**953**	**0.6**	**0.55**	-6.90
75	0.95	3.88	5.40	75	0.133	2.46	15	927	0.7	0.24	-10.63
75	0.86	4.28	5.96	72	0.182	3.05	24	933	1	0.29	-10.49
75	0.65	5.27	12.82	40	0.835	6.51	177	910	8	4.77	-11.74
75	0.35	5.91	19.22	10	1.784	9.28	430	896	24	10.50	-18.64
75	0.00	6.48	20.60	4	1.802	8.75	405	922	20	10.55	-23.51
75	0.00	6.81	17.22	19	1.031	5.99	186	939	7	4.14	-12.29

(Bold indicates pH chosen for the Step-2 of the optimized coagulation)

Table 5-15 Alum-Optimized Coagulation of Bacon Waters

Dose (mg/l)	Acid (meq/L)	Final pH	DOC (mg/l)	% DOC Removal	UV$_{254}$ (cm^{-1})	SUVA (mL/mg)	Color (CU)	Cond. (uS)	Turb. (NTU)	Res. Al^{+3} (mg/L)	Zeta (mV)
Run-off [a]											
10	1.05	4.77	23.55	3	0.948	4.07	122	980	7.0	0.80	-16.54
20	0.98	4.57	23.83	2	0.827	3.47	90	852	7.0	1.29	-18.83
40	0.90	4.43	21.49	12	0.682	3.17	50	1046	2.2	1.62	-3.04
60	0.96	4.52	16.76	31	0.453	2.70	37	995	1.5	1.15	-12.23
80	0.86	4.83	13.36	45	0.335	2.51	24	937	2.4	0.11	-26.37
100	**0.77**	**5.30**	**12.64**	**48**	**0.292**	**2.31**	**21**	**1076**	**2.3**	**0.10**	-2.35
Baseline [b]											
10	1.80	4.5	10.18	9	0.591	5.81	122	498	10.0	0.38	-17.81
20	1.76	4.35	8.02	28	0.416	5.19	70	497	12.0	0.62	-16.98
40	1.67	4.31	5.27	53	0.200	3.80	23	510	2.6	0.80	-8.01
60	1.48	4.8	3.78	66	0.118	3.12	11	506	0.6	0.06	-19.11
80	1.39	4.3	3.4	70	0.093	2.74	10	517	0.5	0.93	7.04
100	**1.20**	**4.32**	**2.95**	**74**	**0.081**	**2.75**	**8**	**515**	**1.0**	**0.82**	-0.55
125	0.94	4.51	3.19	71	0.068	2.13	5	517	4.5	0.21	0
150	0.73	4.63	2.96	73	0.065	2.20	5	504	4.5	0.11	7.87
200	0.22	4.6	2.61	77	0.059	2.26	3	504	4.3	0.07	9.39

[a]Target pH=4.5
[b]Target pH=4.5

[Bold indicates dose chosen (at optimum pH) for the Step-3 of the optimized coagulation]

Table 5-16 Iron-Optimized Coagulation of Bacon Waters

Dose (mg/l)	Acid (meq/L)	Final pH	DOC (mg/l)	% DOC Removal	UV$_{254}$ (cm^{-1})	SUVA (mL/mg)	Color (CU)	Cond. (uS)	Turb. (NTU)	Res. Fe^{+3} (mg/L)	Zeta (mV)
Run-off [a]											
5	0.98	3.95	24.98	0	1.103	4.42	133	1091	9.2	1.89	-1.52
15	0.92	3.91	23.96	2	1.089	4.55	169	1108	10.0	3.05	-8.01
35	0.86	3.57	17.67	27	0.708	4.01	104	1134	12.0	2.09	-7.73
55	0.73	3.50	12.67	48	0.404	3.19	44	1157	8.0	1.22	-4.69
75	**0.55**	**3.45**	**10.87**	**55**	**0.314**	**2.89**	**28**	**1150**	**1.5**	**1.18**	-9.53
95	0.23	3.64	9.59	61	0.234	2.44	21	1146	1.5	0.46	-11.32
Baseline [b]											
5	1.94	3.73	10.53	6	0.644	6.12	137	521	9.0	1.91	-14.91
15	1.84	3.45	9.84	12	0.735	7.47	184	538	14.0	3.19	-36.84
35	1.73	3.4	4.34	61	0.142	3.27	15	550	1.0	0.51	-8.42
55	**1.58**	**3.45**	**2.87**	**74**	**0.083**	**2.89**	**6.5**	**559**	**0.8**	**0.37**	6.15
75	1.41	3.31	2.45	78	0.080	3.27	8.5	571	0.6	0.45	7.04
95	1.20	3.33	2.50	78	0.077	3.08	8	578	0.8	0.42	5.66
120	4.89	3.35	2.17	81	0.082	3.78	15	597	3.7	0.68	9.53
150	3.01	3.55	1.80	84	0.048	2.67	8	550	2.1	0006	-6.49
200	-	3.51	1.81	84	0.042	2.32	5	582	0.5	0.13	11.32

[a]Target pH=4.5
[b]Target pH=3.5

[Bold indicates dose chosen (at optimum pH) for the Step-3 of the optimized coagulation]

Table 5-17 Alum-Optimized Coagulation of Twitchell Waters

Dose (mg/l)	Acid (meq/L)	Final pH	DOC (mg/l)	% DOC Removal	UV_{254} (cm^{-1})	SUVA (mL/mg)	Color (CU)	Cond. (uS)	Turb. (NTU)	Res. Al^{+3} (mg/L)	Zeta (mV)
Run-off [a]											
10	1.09	4.81	43.04	6	1.742	4.05	241	1105	4.0	1.42	-14.77
20	1.00	4.37	43.08	6	1.594	3.70	221	1086	7.0	2.02	-10.77
40	0.85	4.51	39.10	4	1.155	2.95	140	1105	13.0	2.69	-20.71
60	0.68	4.49	32.82	19	0.827	2.52	86	1106	13.0	2.21	-13.95
80	0.53	4.55	25.04	38	0.826	3.30	52	1112	7.4	1.44	-1.66
100	**0.39**	**4.45**	**22.68**	**44**	**0.593**	**2.61**	**229**	**1120**	**3.7**	**1.39**	**-10.63**
Baseline [b]											
10	1.47	3.97	20.56	4	1.023	4.98	181	779	11.0	0.96	-20.57
20	1.39	4.17	19.43	9	0.792	4.08	107	908	7.0	1.49	-16.02
40	1.20	4.43	14.55	32	0.478	3.29	50	910	2.8	1.27	-9.39
60	1.07	4.44	11.25	47	0.326	2.90	34	912	1.5	1.09	-8.42
80	0.83	4.61	8.19	62	0.201	2.45	18	902	2.2	0.35	-5.94
100	**0.66**	**4.55**	**7.10**	**67**	**0.161**	**2.27**	**18**	**917**	**2.2**	**0.47**	**-5.80**
125	2.37	4.46	5.78	73	0.130	2.25	10	909	4.6	0.96	0
150	0.34	4.56	5.43	75	0.119	2.19	8	919	4.5	0.35	0.97
200	0.02	4.47	5.1	76	0.113	2.22	8	925	5.5	0.75	-6.64

[a]Target pH=4.5
[b]Target pH=4.6

[Bold indicates dose chosen (at optimum pH) for the Step-3 of the optimized coagulation]

Table 5-18 Iron-Optimized Coagulation of Twitchell Waters

Dose (mg/l)	Acid (meq/L)	Final pH	DOC (mg/l)	% DOC Removal	UV_{254} (cm^{-1})	SUVA (mL/mg)	Color (CU)	Cond. (uS)	Turb. (NTU)	Res. Fe^{+3} (mg/L)	Zeta (mV)
Run-off [a]											
5	1.50	3.11	37.80	7	1.778	4.70	243	1259	5.5	1.61	-15.6
15	1.41	3.08	37.80	7	1.877	4.97	277	1249	6.5	3.21	-7.87
35	1.22	3.05	35.18	13	1.684	4.79	262	1272	13.0	4.10	-8.42
55	1.03	3.14	22.08	46	0.798	3.61	101	1245	6.7	2.43	-19.63
75	0.88	3.18	15.68	61	0.569	3.63	52	1247	0.9	2.30	46.74
95	**0.70**	**3.21**	**12.51**	**69**	**0.439**	**3.51**	**36**	**1245**	**0.5**	**2.23**	**6.41**
Baseline [b]											
5	1.47	3.24	19.71	8	1.021	5.18	164	990	10.0	2.76	-9.94
15	1.39	3.28	18.84	12	0.997	5.29	160	973	12.0	3.18	-6.77
35	1.20	3.36	12.04	44	0.542	4.50	78	969	7.0	1.84	-7.46
55	1.07	3.53	7.30	66	0.278	3.81	21	945	3.8	0.88	-22.32
75	0.83	3.57	5.43	75	0.161	2.97	8	942	4.2	0.57	-7.32
95	**0.66**	**3.58**	**4.68**	**78**	**0.136**	**2.91**	**8.5**	**948**	**4.4**	**0.63**	**-14.89**
120	2.37	3.61	3.74	83	0.104	2.78	3.3	962	6.8	0.46	1.52
150	0.34	3.64	4.17	80	0.084	2.01	1.8	985	5.8	0.33	-7.09
200	0.02	3.07	3.66	83	0.266	7.27	41	1118	6	3.47	8.7

[a] Target pH= 3.5
[b] Target pH=3.5

[Bold indicates dose chosen (at optimum pH) for the Step-3 of the optimized coagulation]

Table 5-19 Treated Water Characteristics of Delta Waters Derived from Optimized Coagulation

	Bacon				Twitchell			
	Run-off (Event-1)		Baseline (Event-2)		Run-off (Event-1)		Baseline (Event-2)	
	Alum	Iron	Alum	Iron	Alum	Iron	Alum	Iron
Dose (mg/L)	100	85	100	50	100	95	100	85
pH	4.5	3.5	4.5	3.5	4.5	3.5	4.6	3.7
DOC (mg/l)	13.60	10.32	3.11	3.19	22.65	12.64	6.89	5.58
% DOC Removal	44	58	72	71	45	69	68	74
UVA$_{254}$ (cm^{-1})	0.301	0.304	0.095	0.123	0.588	0.449	0.163	0.175
Color (CU)	20	33	16	24	54	37	23	31
Conductivity (uS)	1064	1124	515	561	1081	1206	902	914
Turbidity (NTU)	1.5	1.5	4.2	0.75	2.8	1.5	7.9	7.4
Zeta Potential (mV)	3.5	-7.6	8.5	-3.7	-7.46	-3.38	-3.52	-7.45

Table-5-20 Boundary Conditions of treated water and DOC Removal Models

	Definition (Unit)	Alum (n=84)	Iron (n=77)
pH	raw water pH	7.2 - 7.5	7.2 - 7.5
Alk	raw water alkalinity (mg/L)	60 - 100.8	60 - 100.8
DOC	raw water DOC (mg/L)	11.15 - 40.84	11.15 - 40.84
Dose	coagulant dose (mg/L)	10 - 250	5 - 250
pH$_f$[1]	final pH	2.94 - 6.99	2.66 - 7.04
DOC $_{trt}$	treated water DOC (mg/L)	2.61 - 39.59	1.80 - 39.31
DOC $_{Rem}$	DOC Removal (%)	0.9 % - 76.6%	0.5% - 83.9%

[1] Final pH after adding coagulant and acid/base

Table-5-21 DOC Models

<u>1. Multiple Linear Model</u>

1) Alum
$DOC_{trt} = -0.814 + 0.863*(DOC) - 0.069*(Dose) + 0.428*(pH_f)$
$n=84$, $r^2=0.874$, $F=192.4$

2) Iron
$DOC_{trt} = -7.85 + 0.739*(DOC) - 0.07*(Dose) + 2.3*(pH_f)$
$n=77$, $r^2=0.802$, $F=103.4$

<u>2. Semi-Log Model</u>

1) Alum
$DOC_{trt} = -30.4 + 20.11*\ln(DOC) - 4.47*\ln(Dose) + 2.16*\ln(pH_f)$
$n=84$, $r^2=0.836$, $F=141.8$

2) Iron
$DOC_{trt} = -32.24 + 16.48*\ln(DOC) - 4.79*\ln(Dose) + 10.85*\ln(pH_f)$
$n=77$, $r^2=0.807$, $F=107$

<u>3. Log-Log Model</u>

1) Alum
$\ln(DOC_{trt}) = -0.59 + 1.428*\ln(DOC) - 0.4*\ln(Dose) + 0.231*\ln(pH_f)$
$n=84$, $r^2=0.920$, $F=301.0$

2) Iron
$\ln(DOC_{trt}) = -1.598 + 1.381*\ln(DOC) - 0.431*\ln(Dose) + 0.982*\ln(pH_f)$
$n=77$, $r^2=0.895$, $F=217$

Note : These models are valid only for 20°C.

Table-5-22 DOC Percent Removal Models

1. Multiple Linear Model

1) Alum
$DOC_{Rem} = 0.433 - 0.0083*(DOC) + 0.0031*(Dose) - 0.0254*(pH_f)$
n=84, r^2=0.647, F=51.8

2) Iron
$DOC_{Rem} = 0.822 - 0.0066*(DOC) + 0.0306*(Dose) - 0.106*(pH_f)$
n=77, r^2=0.688, F=56.8

2. Semi-Log Model

1) Alum
$DOC_{Rem} = 0.268 - 0.231*ln(DOC) + 0.234*ln(Dose) - 0.1*ln(pH_f)$
n=84, r^2=0.748, F=82.9

2) Iron
$DOC_{Rem} = 0.776 - 0.159*ln(DOC) + 0.215*ln(Dose) - 0.502*ln(pH_f)$
n=77, r^2=0.783, F=92.5

3. Log-Log Model

1) Alum
$ln(DOC_{Rem}) = -4.91 - 0.681*ln(DOC) + 1.26*ln(Dose) + 0.185*ln(pH_f)$
n=84, r^2=0.56, F=35.2

2) Iron
$ln(DOC_{trt}) = -0.473 - 0.472*ln(DOC) + 0.875*ln(Dose) - 2.1*ln(pH_f)$
n=77, r^2=0.646, F=47.1

Note: These models are valid only for 20°C.

Table-23 Summary of Index of Agreement Analysis of DOC Models

		Cases within 25% of Measured Value	
	Total # of cases	# of cases	%
Alum	84	65	77%
Iron	77	45	58%

Figure 5-1 Raw water Quality
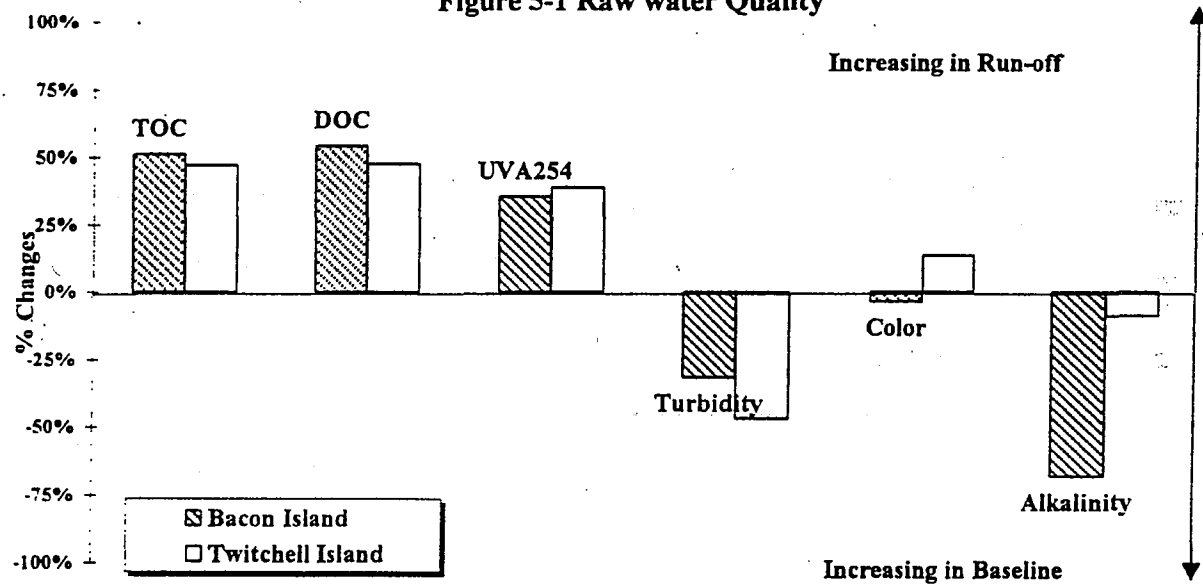
Figure 5-2: Titration curves for Bacon waters with 0.5% H_2SO_4
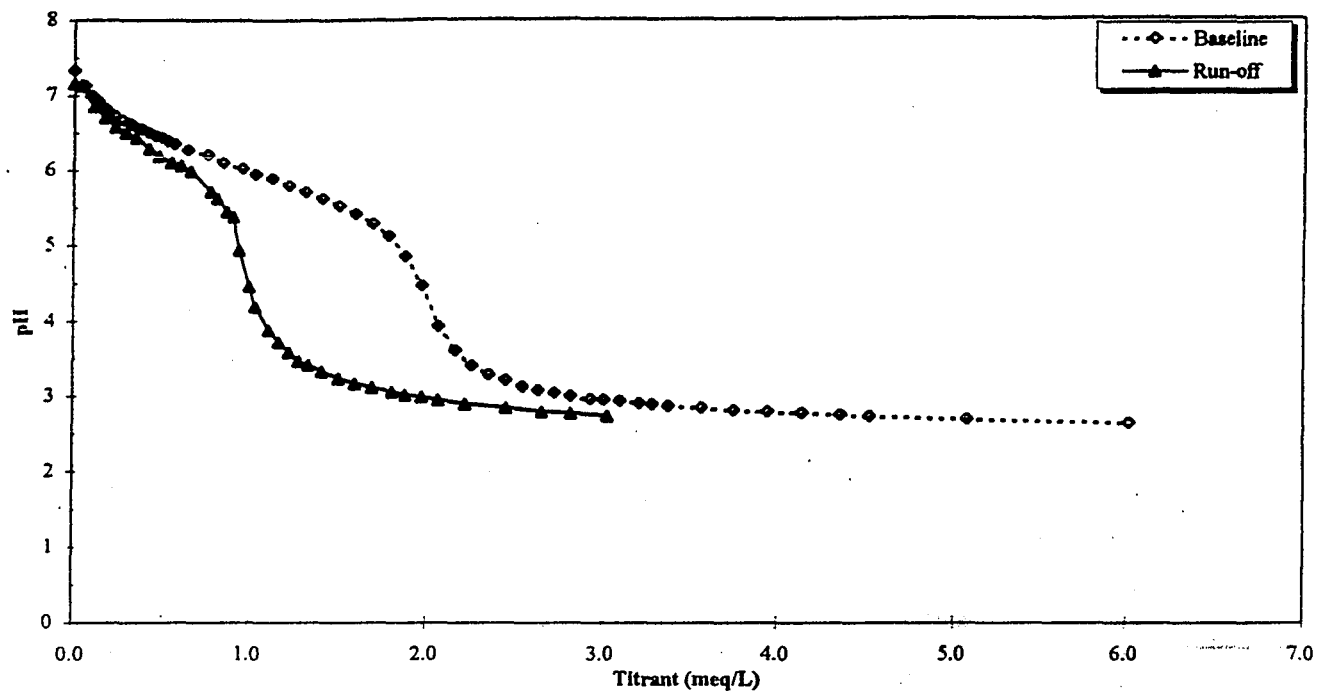
Figure 5-3:Titration curves for Twitchell waters with 0.5% H_2SO_4
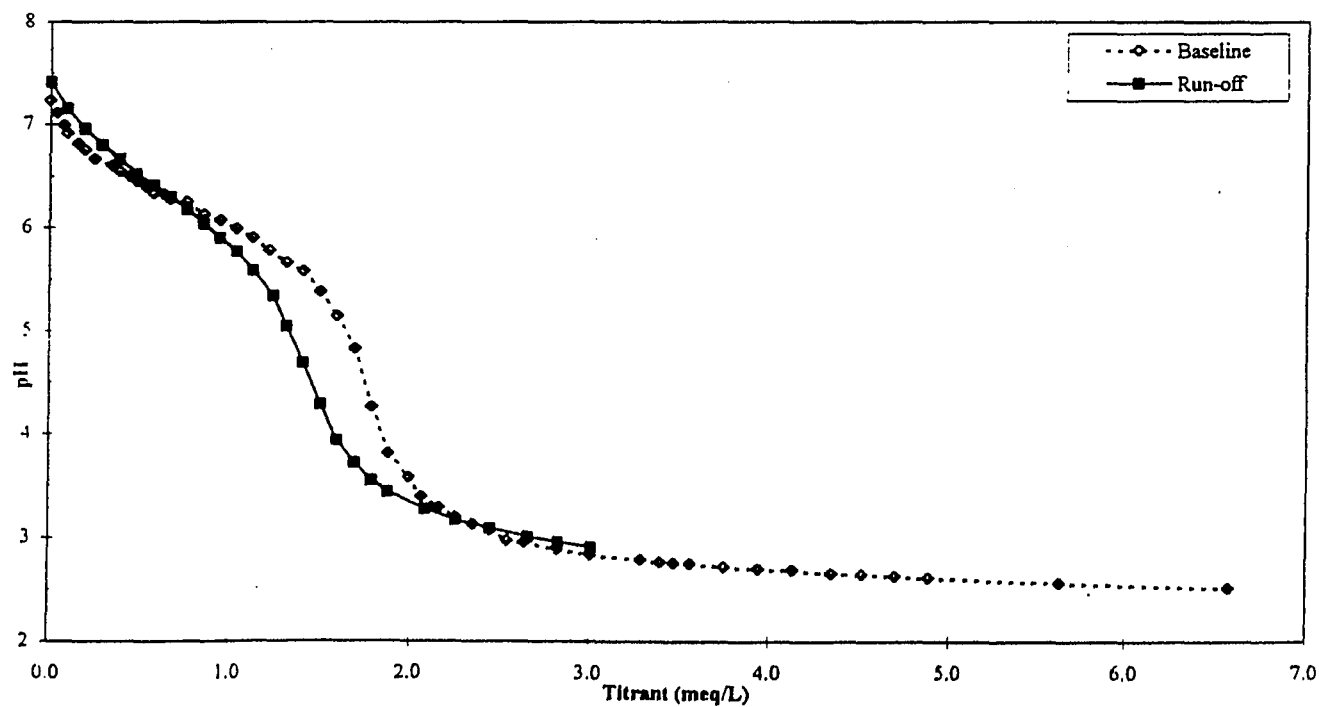
Figure 5-4: Titration curves for Bacon waters with 0.5% Alum
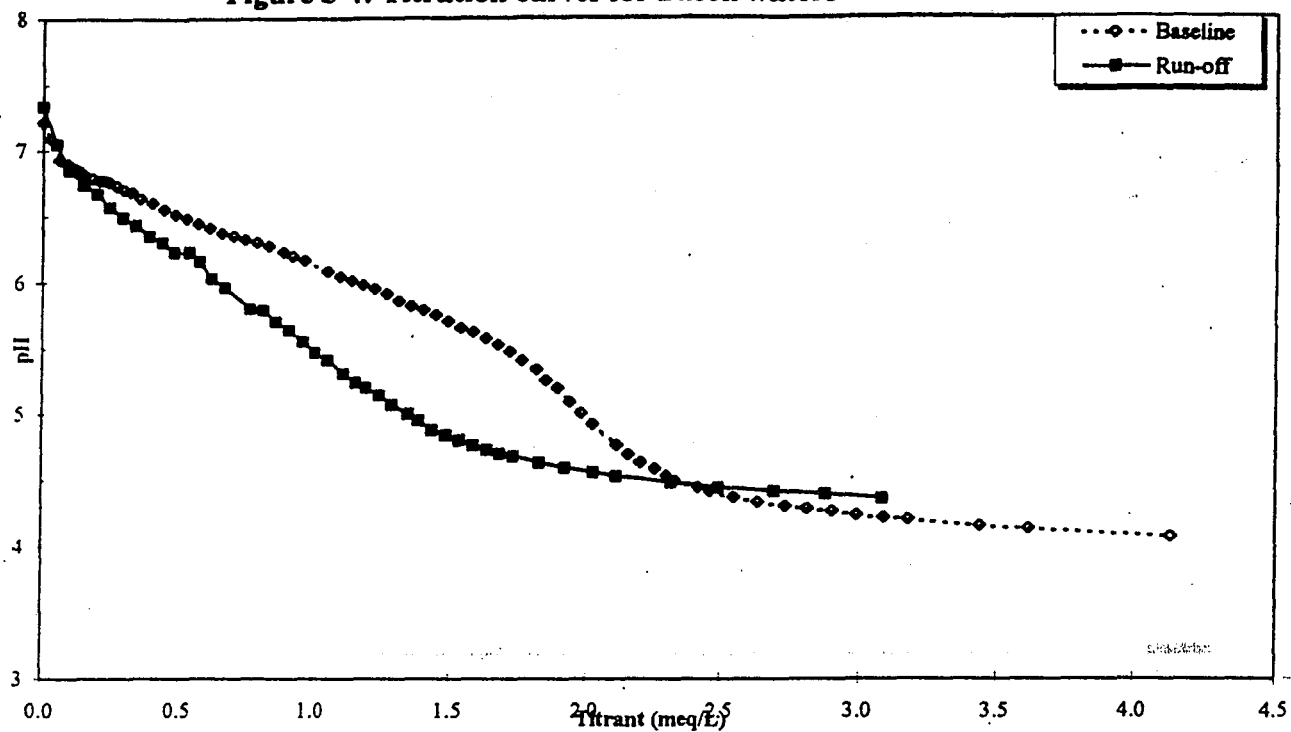
Figure 5-5: Titration curves for Twitchell waters with 0.5% alum

44
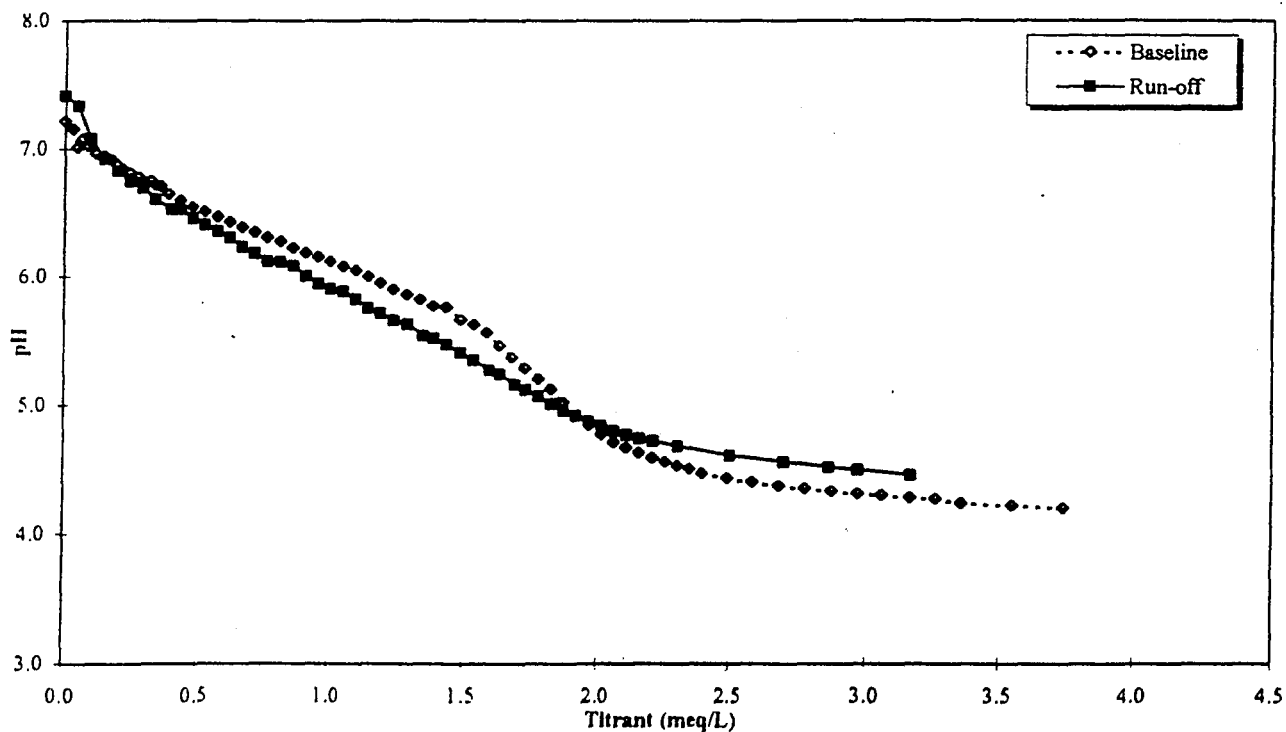
Figure-5-6: Titration curves for Bacon waters with 0.5% Iron
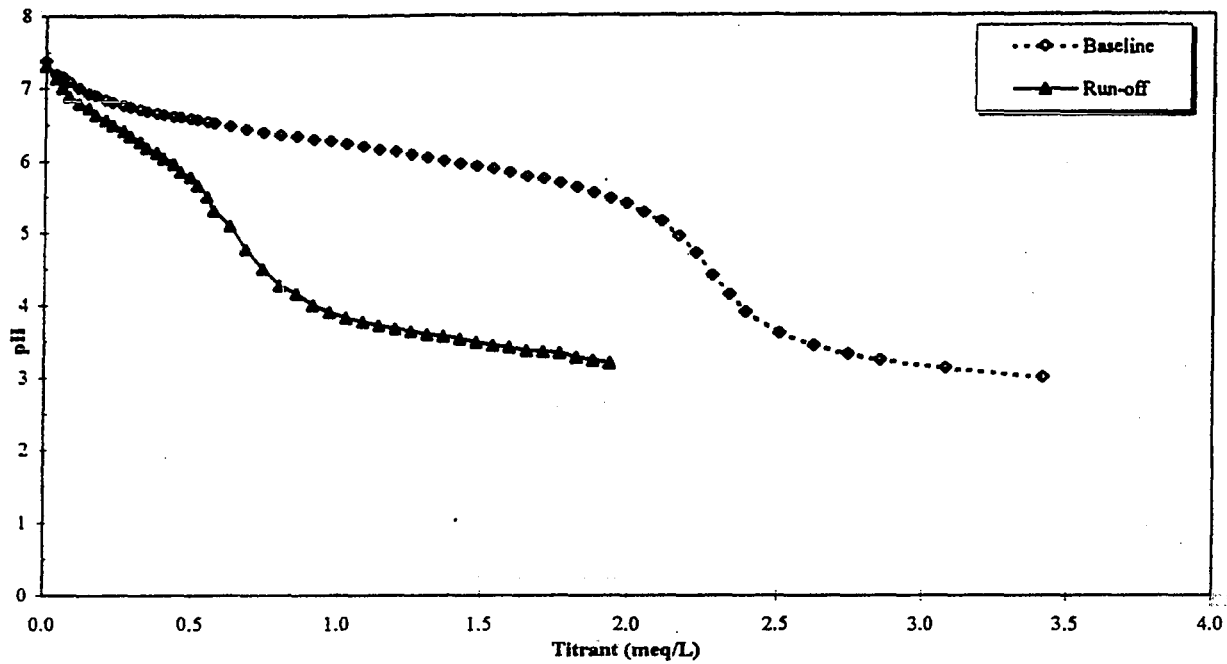
Figure 5-7: Titration curves for Twitchell rwaters with 0.5% iron
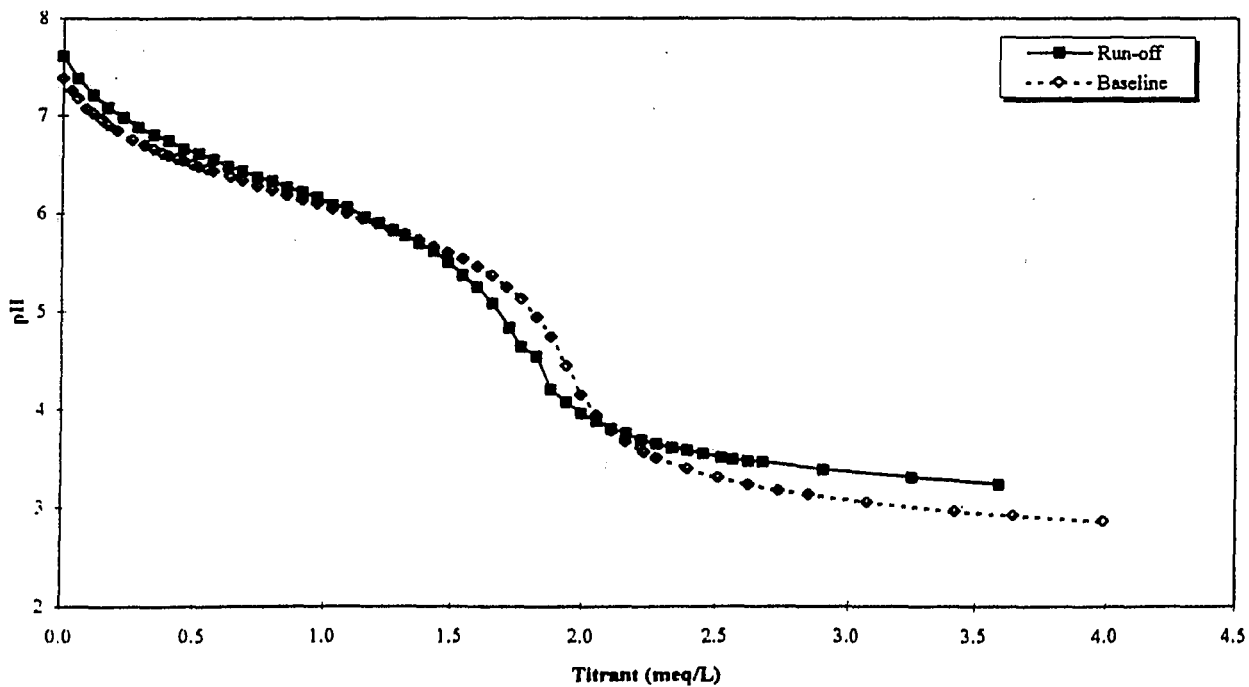
Figure 5-8: Steps in evaluating optimum coagulation

Step-1: Determine the preliminary dose:

A minimum dose is selected from a series of jar-tests performed under ambient conditions (i.e. enhanced coagulation). Selected dose is such that there would be significant but not maximum DOC removal.

Step-2: Determine the optimum pH:

Next a series of jar-tests are conducted at the preliminary dose (evaluated from step-1), over a pH range of 3.0-7.0 in 0.5 pH increments. Objective is to evaluate the optimum pH that would be most effective in DOC removal.

Step-3: Determine the optimum dose at the optimum pH:

More jar-tests to evaluate the optimum dose at this optimum-pH. Dose is chosen that is most effective in DOC removal. Zeta potential is also evaluated for floc stability.

Figure 5-9: Enhanced Coagulation with Alum for Bacon Waters

Run-off
Step-1: (25 mg/L selected as preliminary dose)

Baseline
Step-1 : (50 mg/L selected as preliminary dose)

Legend: Run-off (DOC) — Baseline (DOC) — Run-off (UVA254) — Baseline (UVA)

X-axis: Dose (mg/L)
Left Y-axis: DOC (mg/L)
Right Y-axis: UVA 254
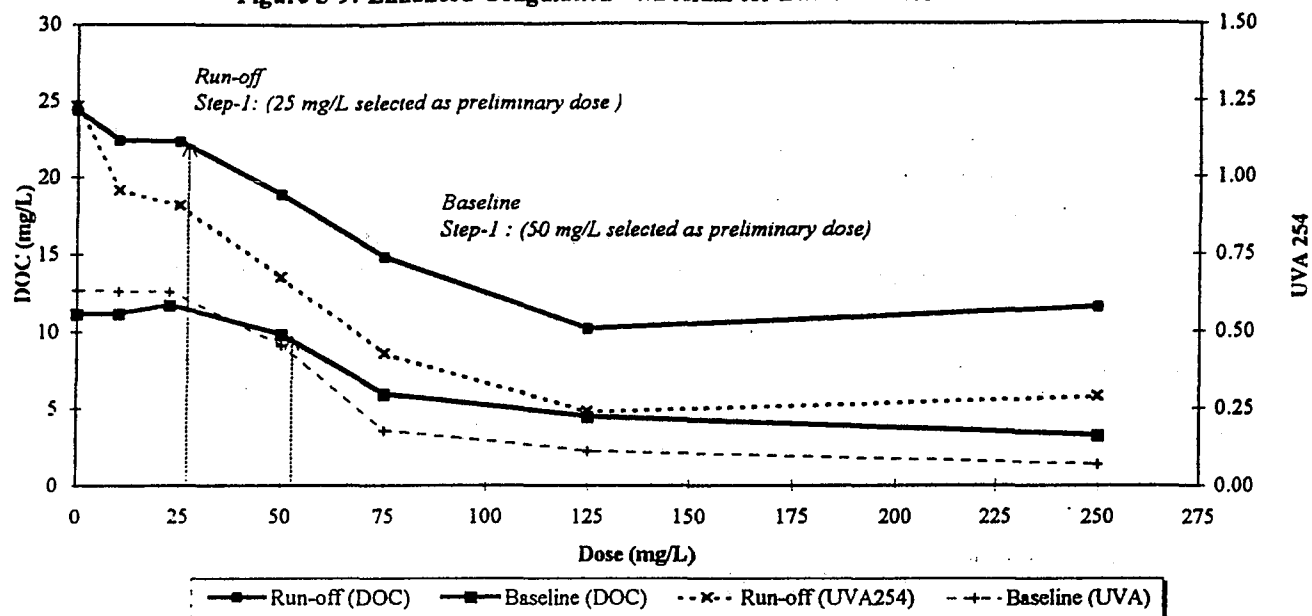
Figure-5-10: Alum-pH Scan for Bacon Waters

Run-off:
Step- 2: (pH ~4.5 is taken as the optimum pH)

Baseline:
Step-2 : (The optimum pH ~4.5)

Legend: Run-off (DOC) — Baseline (DOC) — Run-off (UVA) — Baseline(UVA)

X-axis: pH
Left Y-axis: DOC (mg/L.)
Right Y-axis: UVA254
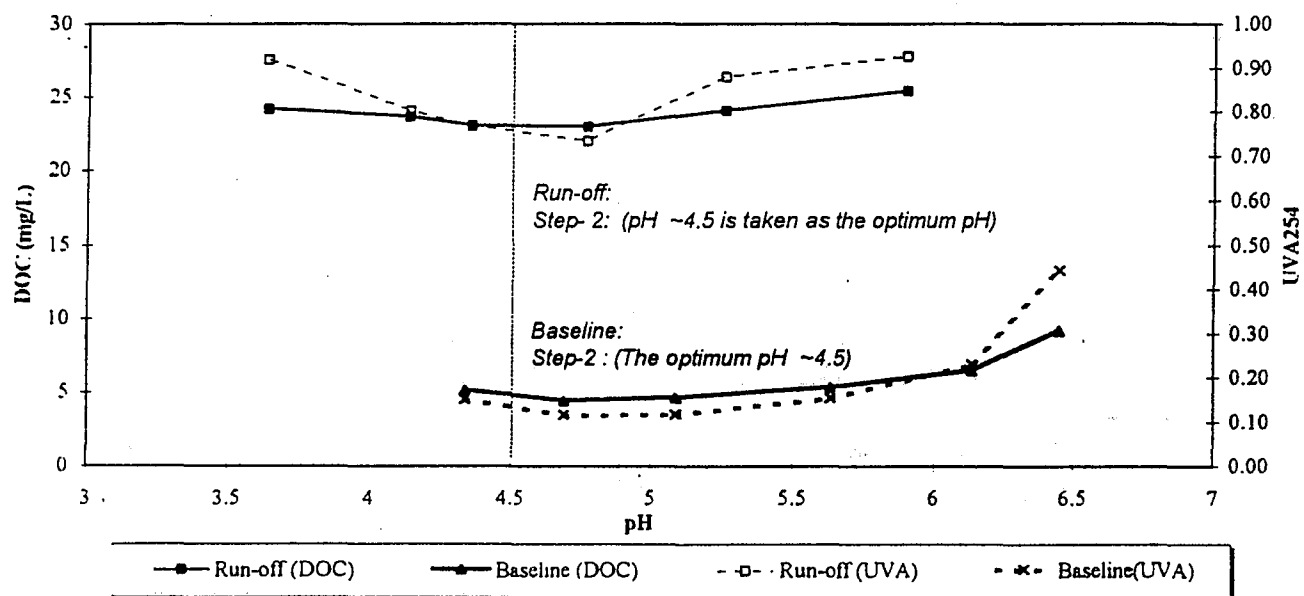
Figure 5-11: Alum-Dose Scan for Bacon Waters

Runoff:
Step-3: (100 mg/L at pH 4.5 is taken as the optimum dose)

Baseline:
Step-3: (100 mg/L at pH 4.5 is taken as the optimum dose)

Legend: Run-off (DOC) — Baseline (DOC) — Run-off (UVA) — Baseline (UVA)

Dose (mg/L)
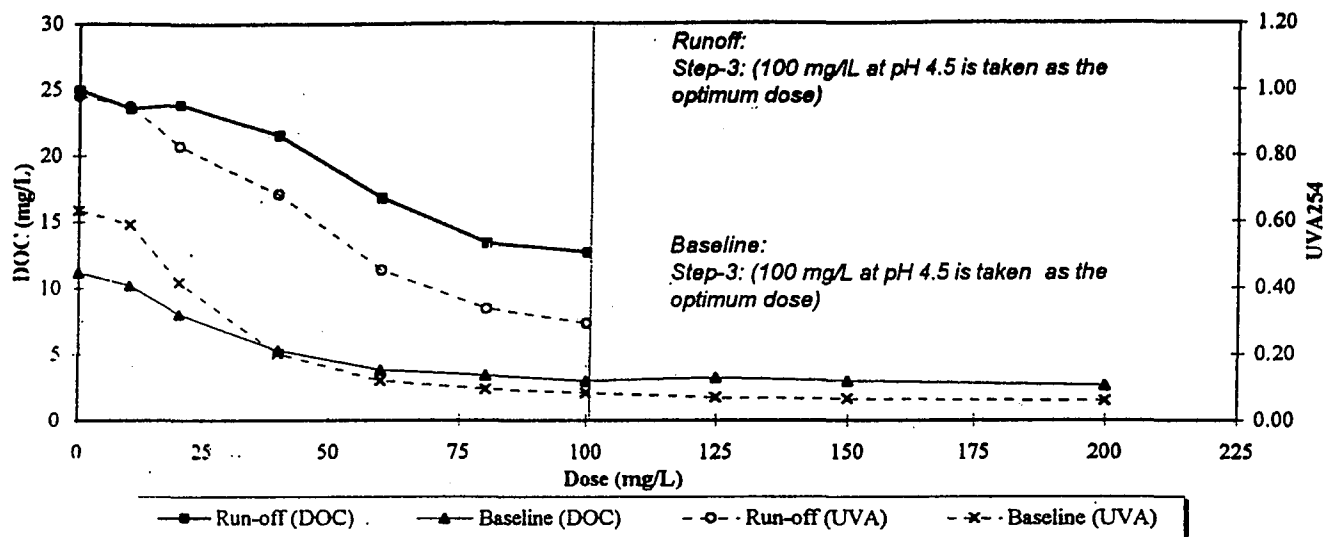
Figure 5-12: Enhanced Coagulation with Iron for Bacon Waters

Baseline
Step-1 : (75 mg/L selected as preliminary dose)

Legend: Baseline (DOC) — Baseline (UVA)

Dose (mg/L)
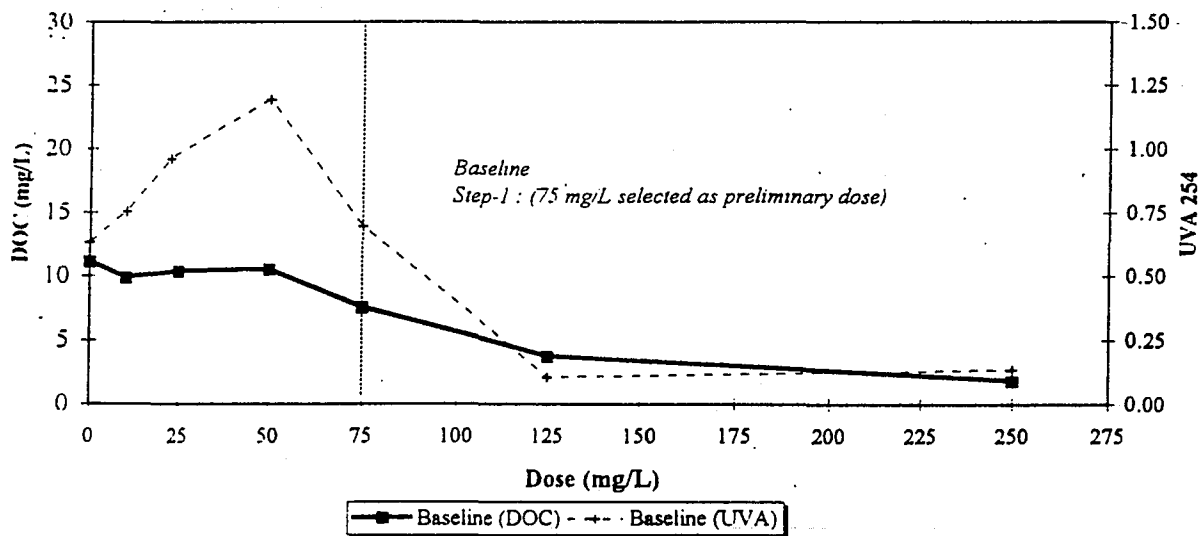
Figure-5-13: Iron-pH Scan for Bacon Waters

Run-off:
step-2 The optimum pH ~ 4.5

Baseline:
Step-2 The optimum pH ~3.5

Run-off (DOC)   Baseline (DOC)   - -□- - Run-off (UVA)   - -✕- - Baseline(UVA)
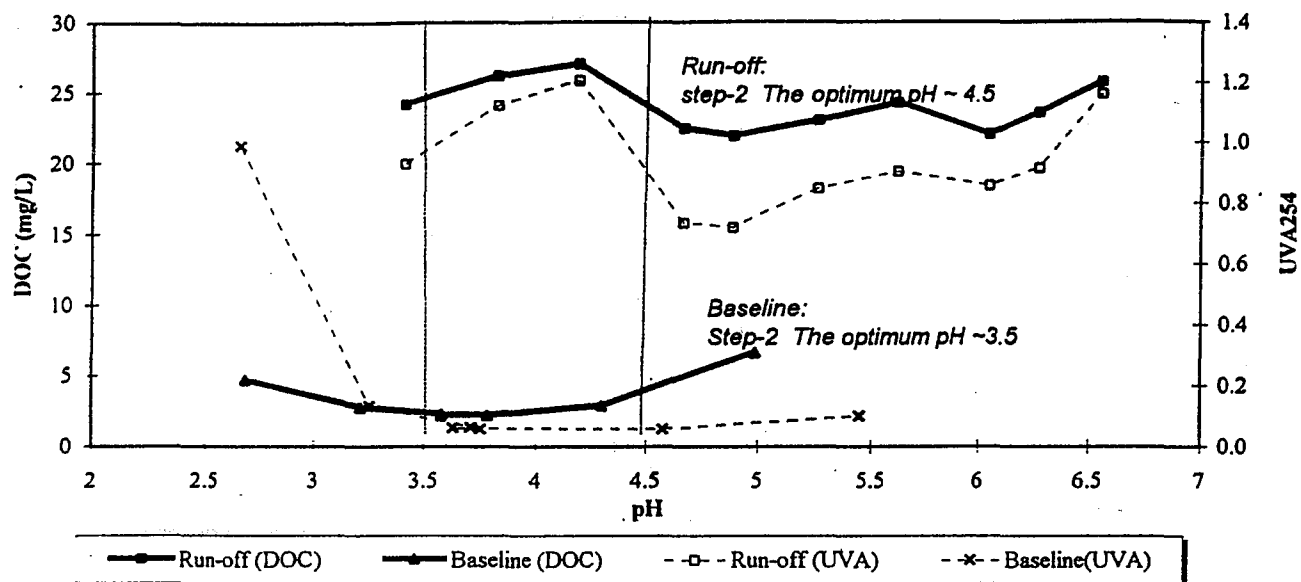
Figure-5-14: Iron-Dose Scan for Bacon Waters

Run-off:
Step-3: (85 mg/L at pH 4.5 is taken as the
optimum dose)

Baseline:
Step-3: (50 mg/L at pH 3.5 is taken as the
optimum dose)

Run-off (DOC)   Baseline (DOC)   - -○- - Run-off (UVA)   - -✕- - Baseline (UVA)
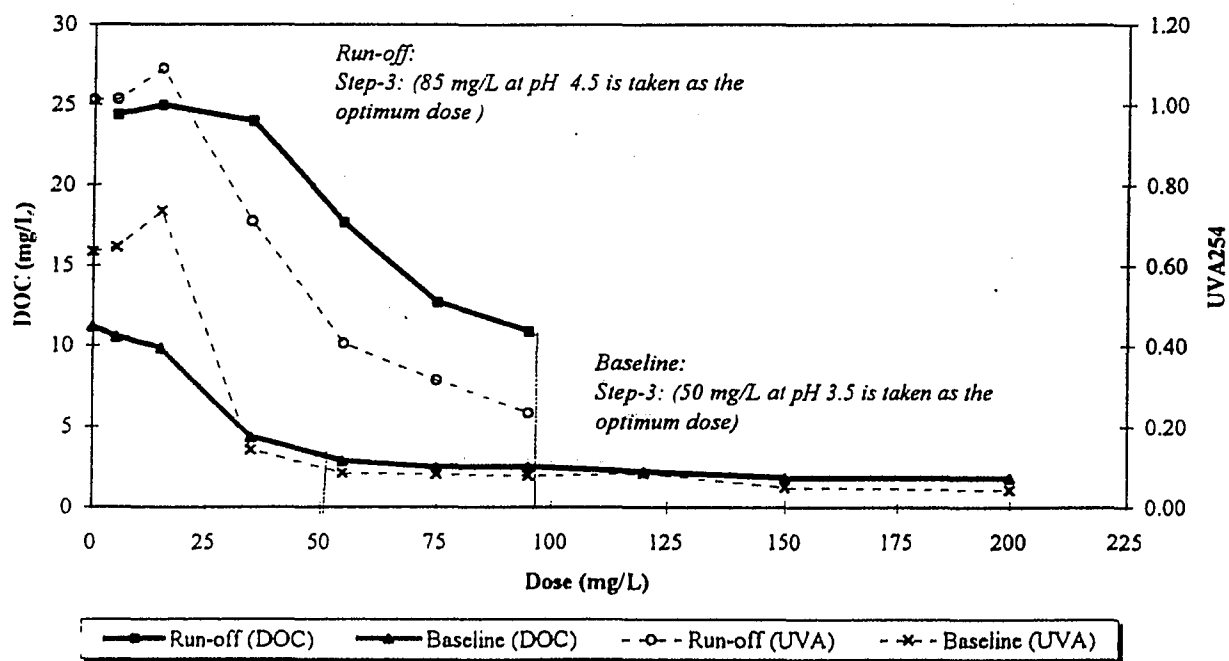
Figure 5-15: Enhanced coagulation with Alum for Twitchell Waters

Run-off
Step-1: (75 mg/L selected as preliminary dose)

Baseline
Step-1 : (50 mg/L selected as preliminary dose)

Legend: Run-off (DOC) Baseline (DOC) ··×·· Run-off (UVA254) ·–+·· Baseline (UVA)
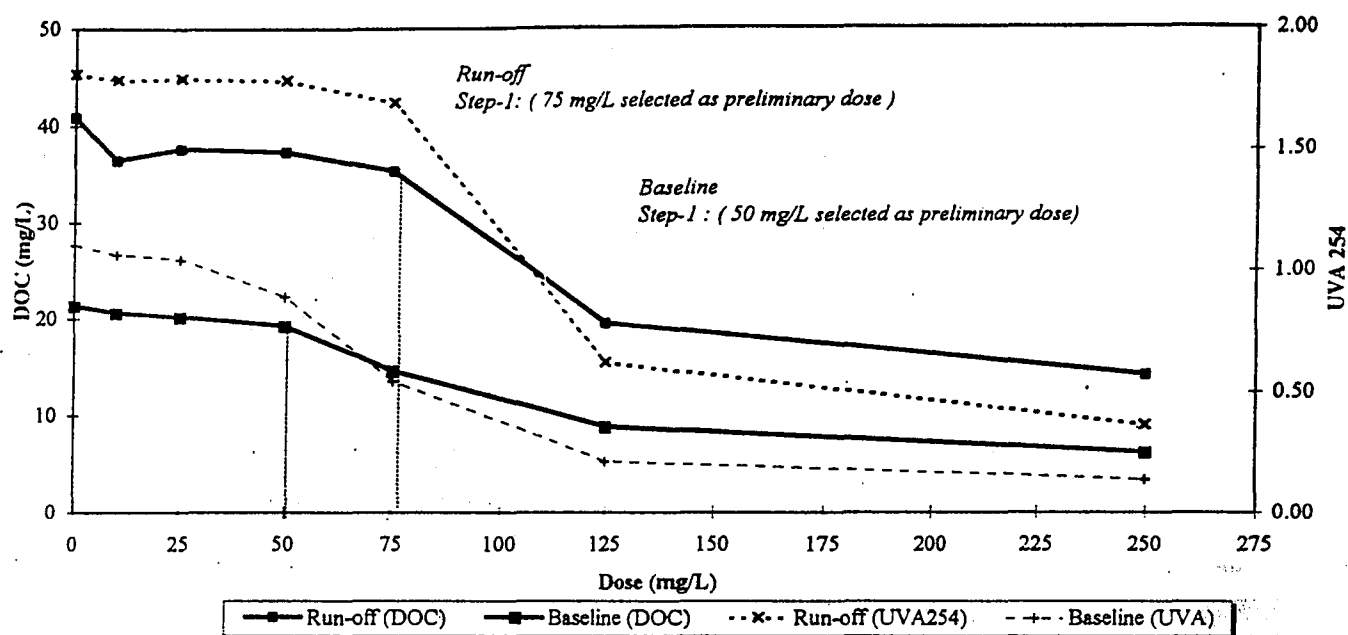
Figure-5-16: Alum-pH Scan for Twitchell Waters

Step-2 : (Thr optimum pH for both occurs at pH 4.5)

Run-off

Baseline

Legend: Run-off (DOC) Baseline (DOC) -□- Run-off (UVA) -×- Baseline(UVA)
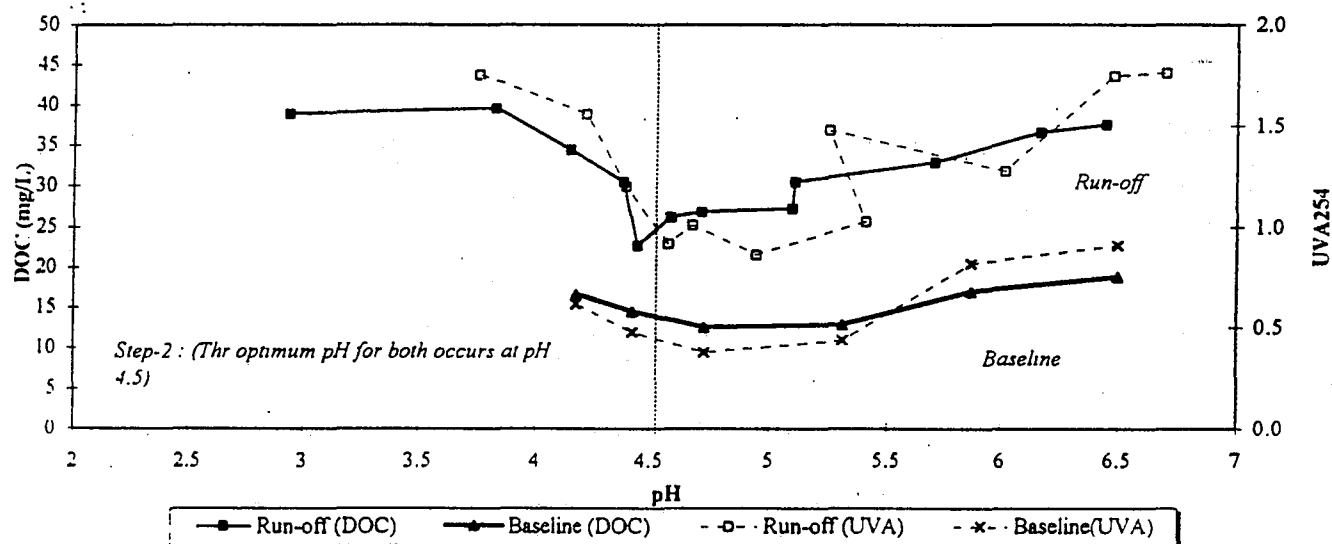
Figure-5-17: Alum-Dose Scan for Twitchell Waters

Run-off:
Step-3: (100 mg/L at pH 4.5 is taken as the Optimum dose)

Baseline:
Step-3: (100 mg/L at pH 4.6 is taken as the Optimum dose)

Legend: Run-off (DOC), Baseline (DOC), Run-off (UVA), Baseline (UVA)
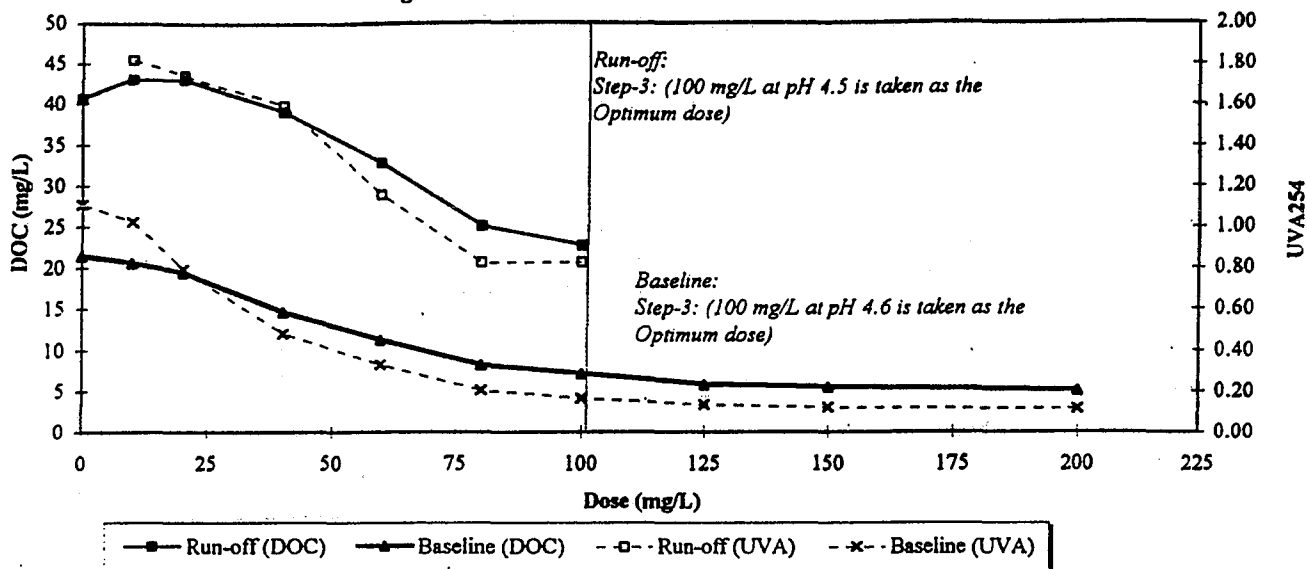
Figure 5-18: Enhanced Coagulation with Iron for Twitchell Waters

Run-off
Step-1:(75 mg/L selected as preliminary dose)

Baseline
Step-1 : (75 mg/L selected as preliminary dose)

Legend: Run-off (DOC), Baseline (DOC), Run-off (UVA254), Baseline (UVA)

Figure 5-19: Iron-pH Scan for Twitchell Waters

Baseline & Run-off:
Step-2: (The optimum pH for both occurs at pH 3.5)

Run-off

Baseline

Legend: ■ Run-off (DOC) ♦ Baseline (DOC) - ▫ - Run-off (UVA) - ✗ - Baseline(UVA)

Figure 5-20: Iron-Dose Scan for Twitchell Waters

Run-off:
Step-3: (95 mg/L at pH 3.5 is taken as the Optimum dose)

Baseline:
Step-3: (85 mg/L at pH 3.5 is taken as the optimum dose)

Legend: ■ Run-off (DOC) ♦ Baseline (DOC) - ▫ - Run-off (UVA) - ✗ - Baseline (UVA)

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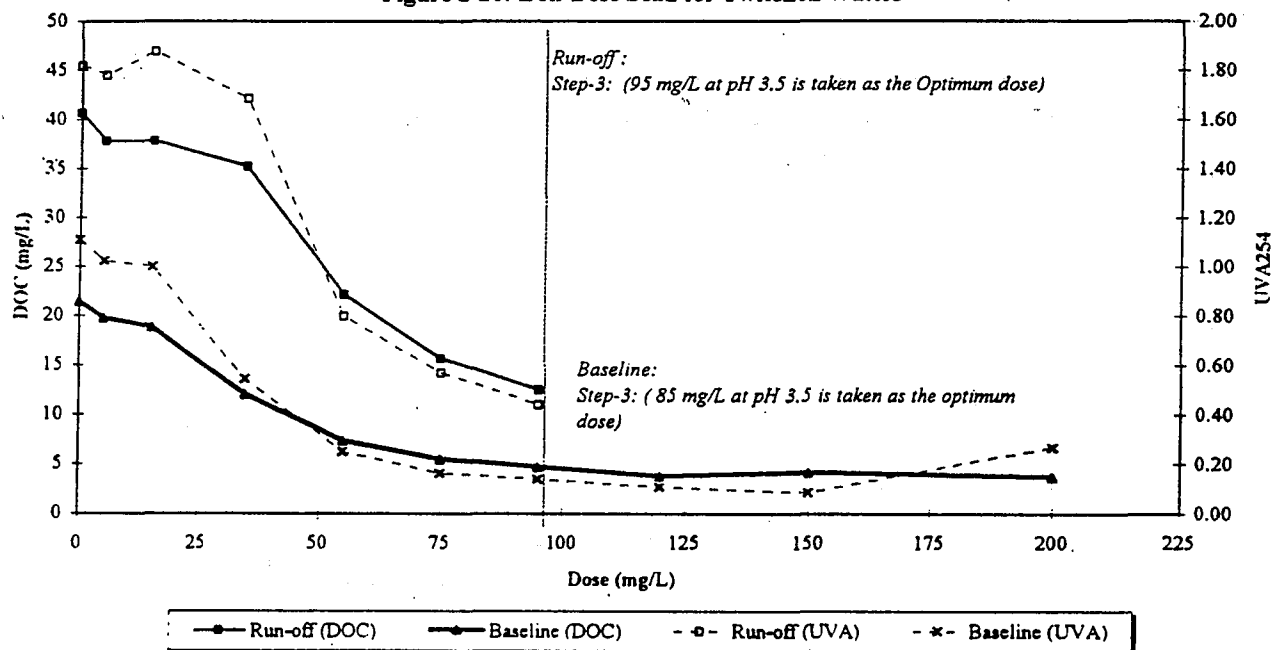
Figure-5-21: Alum-Enhanced vs. Optimized Coagulation for Bacon Waters

Legend:
- ··O·· Enhanced (Run-off)
- ··✱·· Enhanced (Baseline)
- ■ Optimized (Run-off)
- ▲ Optimized (Baseline)
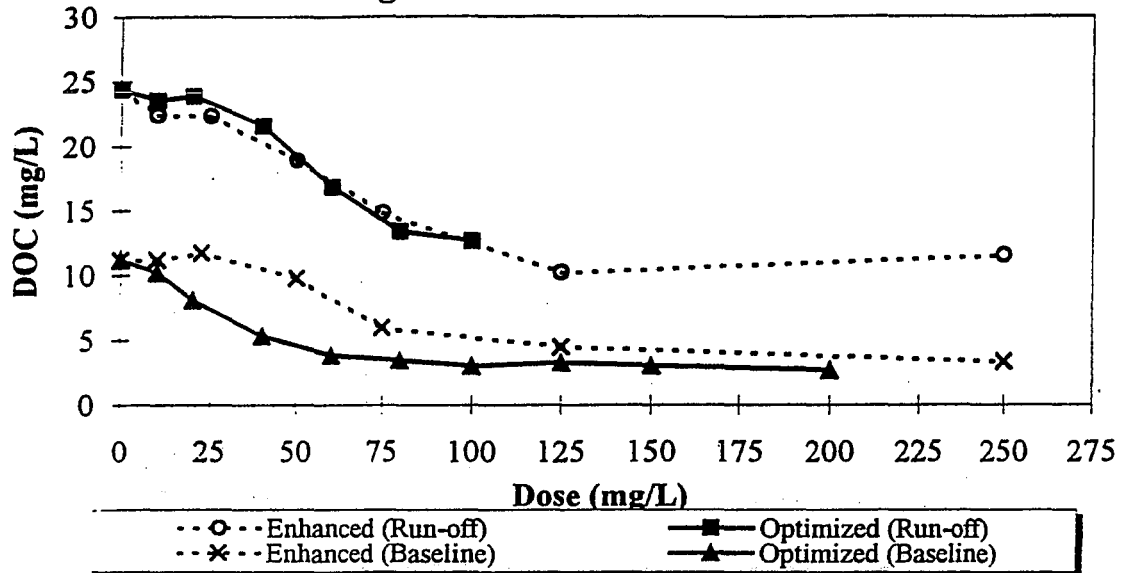
Figure-5-22: Iron-Enhanced vs. Optimized Coagulation for Bacon Waters

Legend:
- ■ Optimized (Run-off)
- ▲ Optimized (Baseline)
- ··✱·· Enhanced (Baseline)

Figure-5-23: Alum-Enhanced vs. Optimized Coagulation for Twitchell Waters

Figure-5-23: Alum-Enhanced vs. Optimized Coagulation for Twitchell Waters
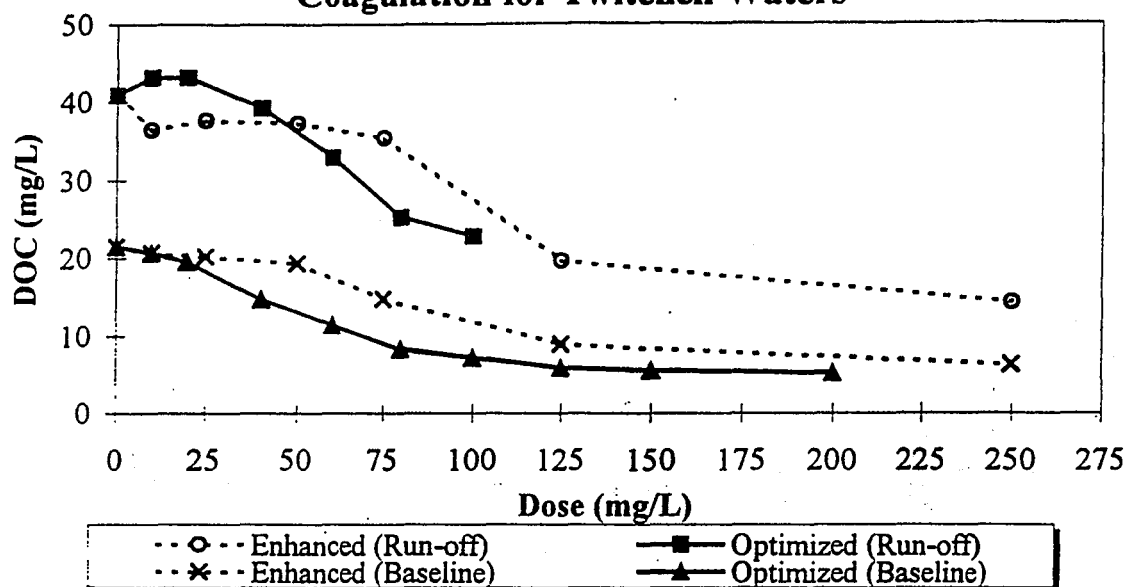
Legend:
- ··O·· Enhanced (Run-off)
- ··✕·· Enhanced (Baseline)
- ■ Optimized (Run-off)
- ▲ Optimized (Baseline)

Figure-5-24: Iron-Enhanced vs. Optimized Coagulation for Twitchell Waters

Figure-5-24: Iron-Enhanced vs. Optimized Coagulation for Twitchell Waters

Legend:
- ··O·· Enhanced (Run-off)
- ··✕·· Enhanced (Baseline)
- ■ Optimized (Run-off)
- ▲ Optimized (Baseline)

54
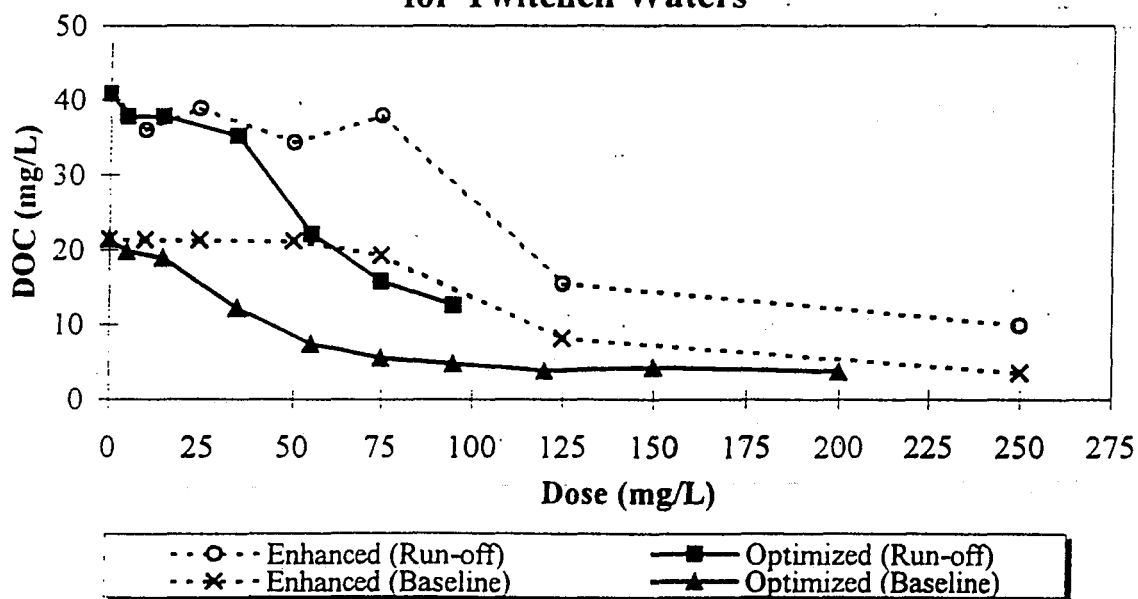
Figure-5-25: DOC Removal of Enhanced vs. Optimized Coagulation (Run-Off)

Enhanced Coagulation
Optimized Coagulation

Bacon Alum — Dose=75mg/L pH=5.97 — Dose=80mg/L pH=4.83

Bacon Iron — Dose=80mg/L pH=3.47

Twitch Alum — Dose=75mg/L pH=6.16 — Dose=80mg/L pH=4.41

Twitch Iron — Dose=75mg/L pH=5.64 — Dose=75mg/L pH=3.16
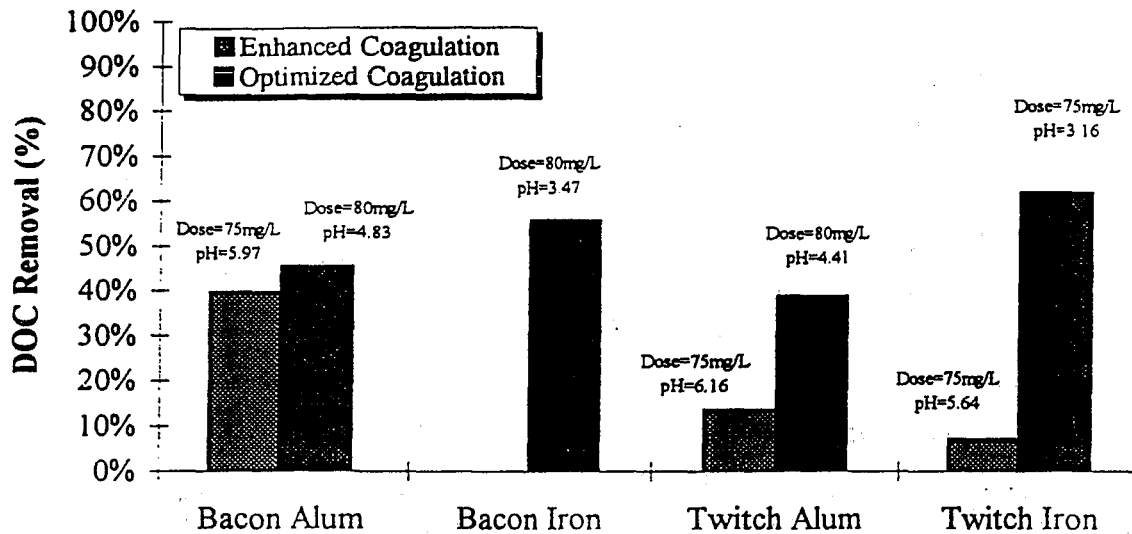
Figure-5-26: DOC Removal of Enhanced vs. Optimized Coagulation (Baseline)

Enhanced Coagulation
Optimized Coagulation

Bacon Alum — Dose=75mg/L pH=6.08 — Dose=80mg/L pH=4.3

Bacon Iron — Dose=75mg/L pH=5.95 — Dose=80mg/L pH=3.31

Twitch Alum — Dose=75mg/L pH=6.08 — Dose=75mg/L pH=4.4

Twitch Iron — Dose=75mg/L pH=5.93 — Dose=75mg/L pH=3.53
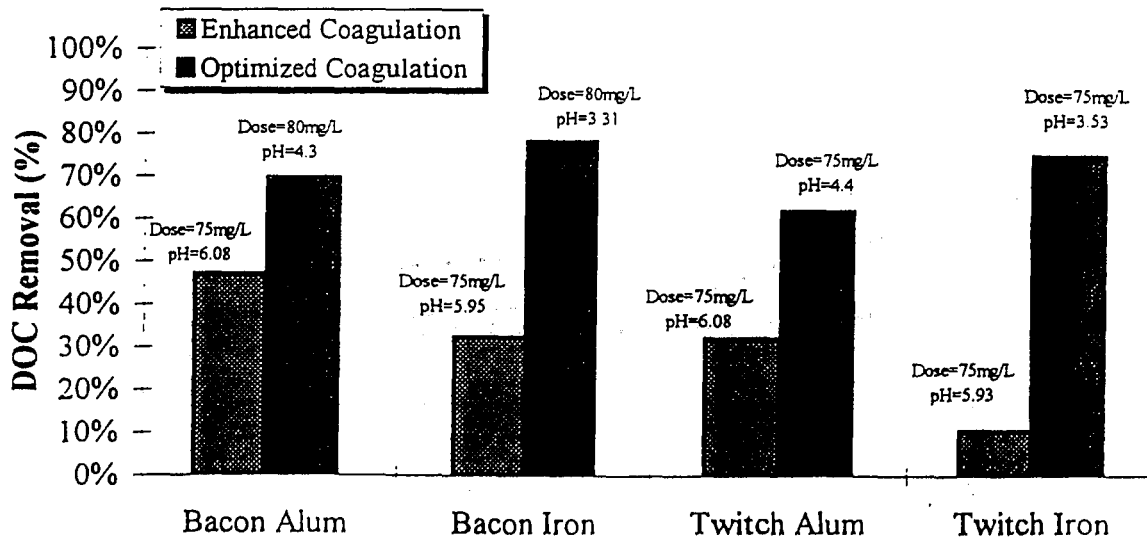
Figure-5-27: Enhanced Alum vs. Enhanced Iron Coagulation for Bacon Waters
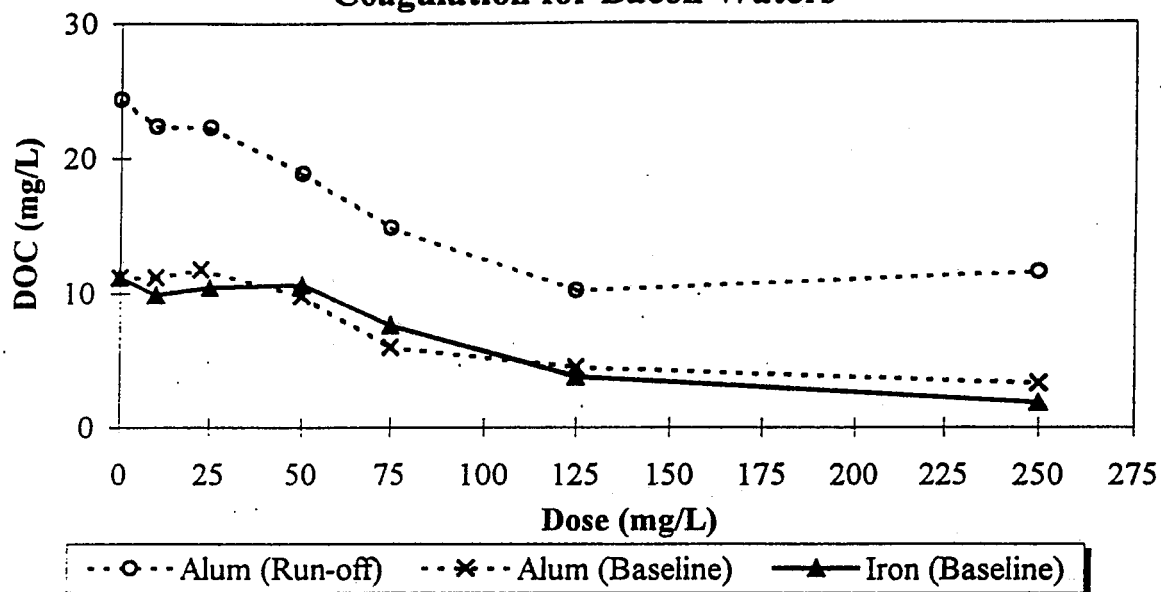
Figure-5-28: Optimized Alum vs. Optimized Iron Coagulation for Bacon Waters
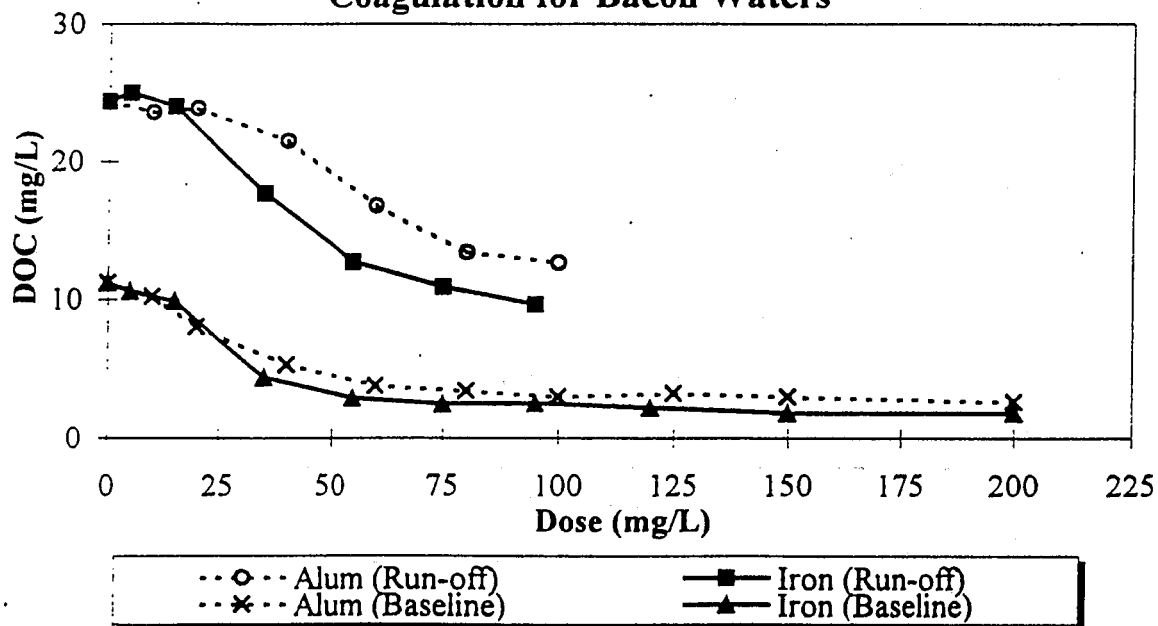
Figure-5-29: Enhanced Alum vs. Enhanced Iron Coagulation for Twitchell Waters
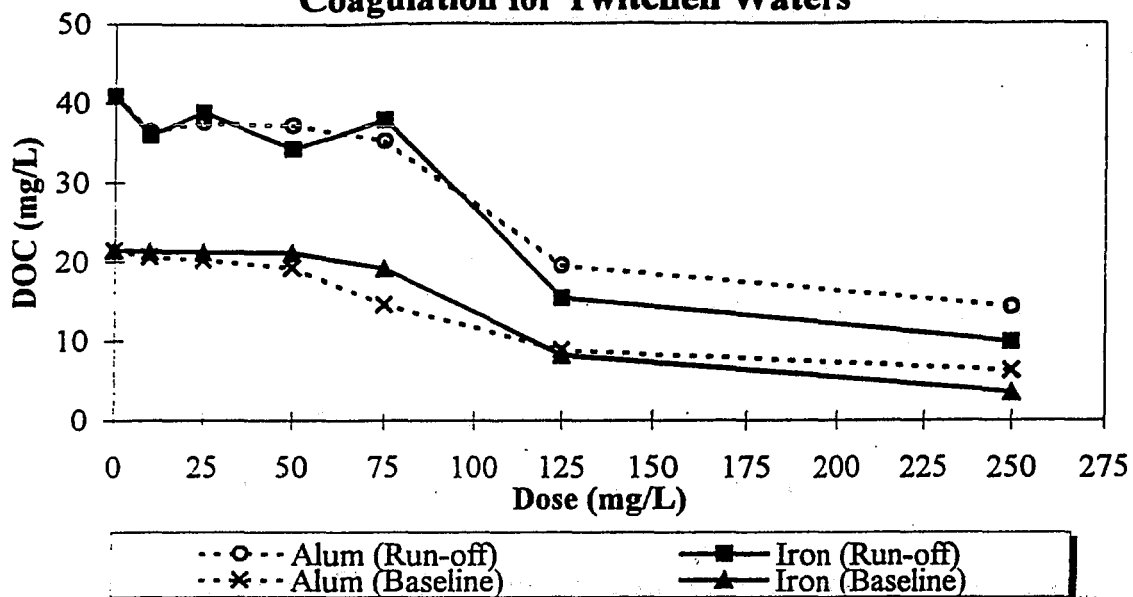
Figure-5-30: Optimized Alum vs. Optimized Iron Coagulation for Twitchell Waters
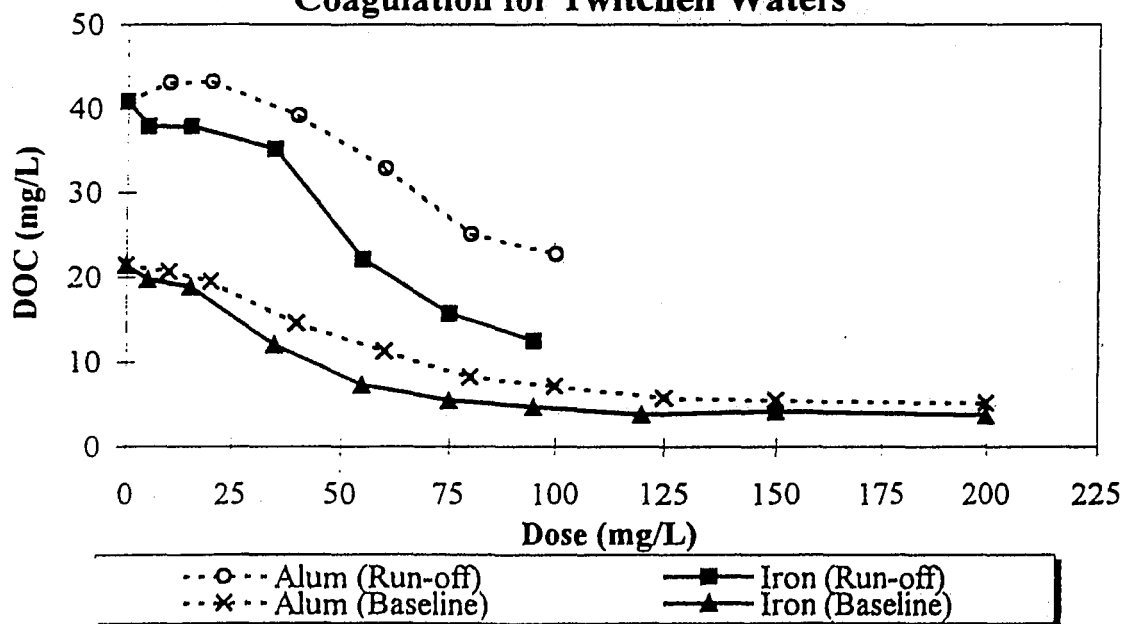
Figure 5-31: Region of Optimized and Enhanced Coagulation in Alum Stability Diagram

Charge Neutralization:
Optimized Coagulation

Bacon Island:
Run-off: 100 mg/L. Initial pH* ~6.0, Final pH 4.5
Baseline: 100 mg/L. Initial pH* ~5.8. Final pH 4.5

Twitchell:
Run-off: 100 mg/L. Initial pH*~6.0, Final pH 4.5
Baseline: 100 mg/L, Initial pH*~6.1, Final pH 4.6

* Coagulation pH after acid, but before coagulant addition

Sweep Coagulation:
Enhanced Coagulation

Bacon Island:
Run-off: 125 mg/L, Initial pH ~ 7.5, Final pH 5.1
Baseline: 125 mg/L, Initial pH ~ 7.3, Final pH 6.0

Twitchell Island:
Run-off: 125 mg/L, Initial pH ~ 7.4, Final pH ~6
Baseline: 125 mg/L, Initial pH ~ 7.2, Final pH ~6

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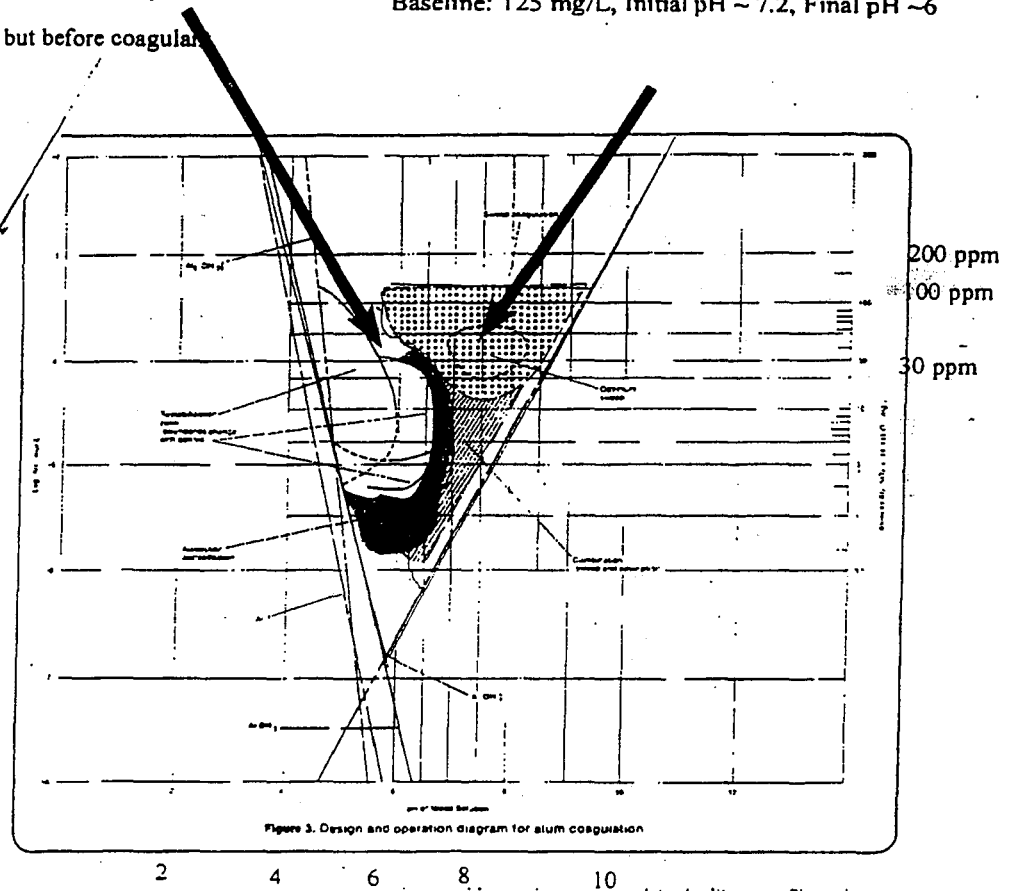
Figure 5-32 Regions of Optimized and Enhanced Coagulation in Iron Stability Diagram

Charge-Neutralization Zone:

Optimized Coagulation:

Bacon:
Run-off: 85 mg/L@ pH* ~5.5, Final pH 3.5
Baseline: 50 mg/L @pH*~ 5.5, Final pH 3.5

Twitchell:
Run-off: 95 mg/L@ pH* ~5.5, Final pH 3.5
Baseline: 85 mg/L@ pH* ~5.7, Final pH 3.5

* Coagulation pH after acid, but before coagulant addition

Sweep Coagulation

Enhanced Coagulation:

Bacon:
Baseline: 125 mg/, Intial pH 7.1, Final pH~4

Twitchell:
Run-off:125 mg/L , Intial pH 7.1, Final pH~5
Baseline:125 mg/L , Intial pH 7.1, Final pH~6

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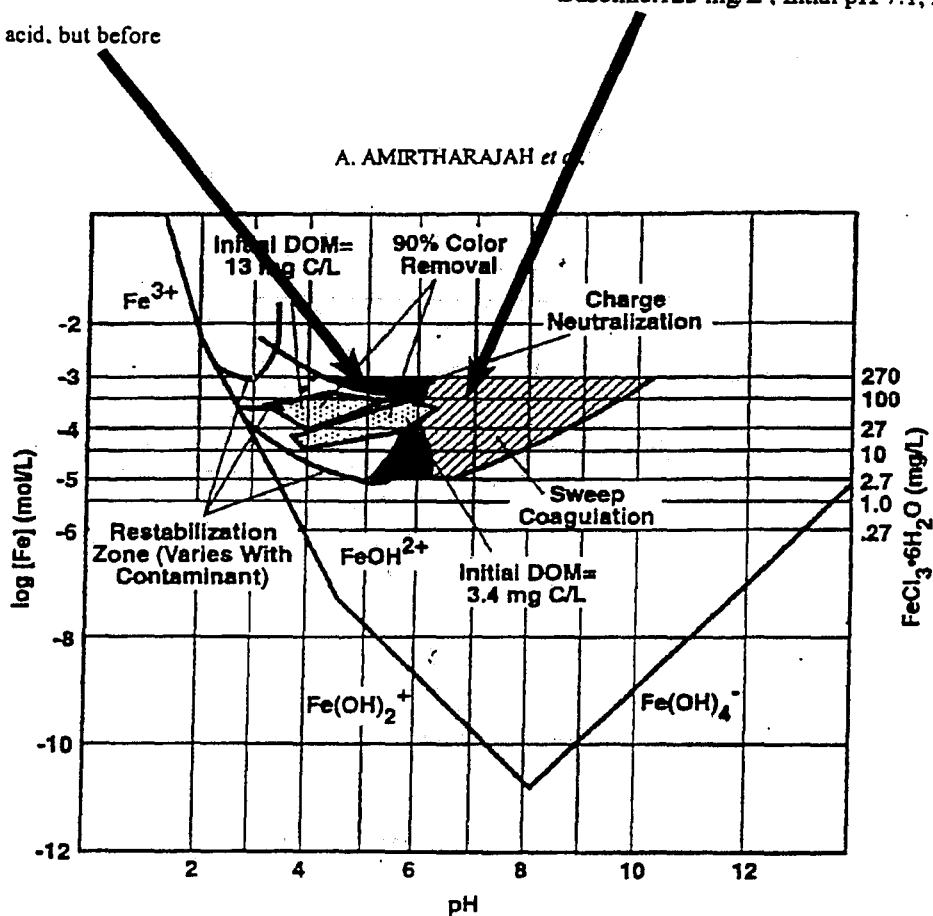
Figure-5-33: Bacon, Percent Removal in Raw vs Optimized Treated Water
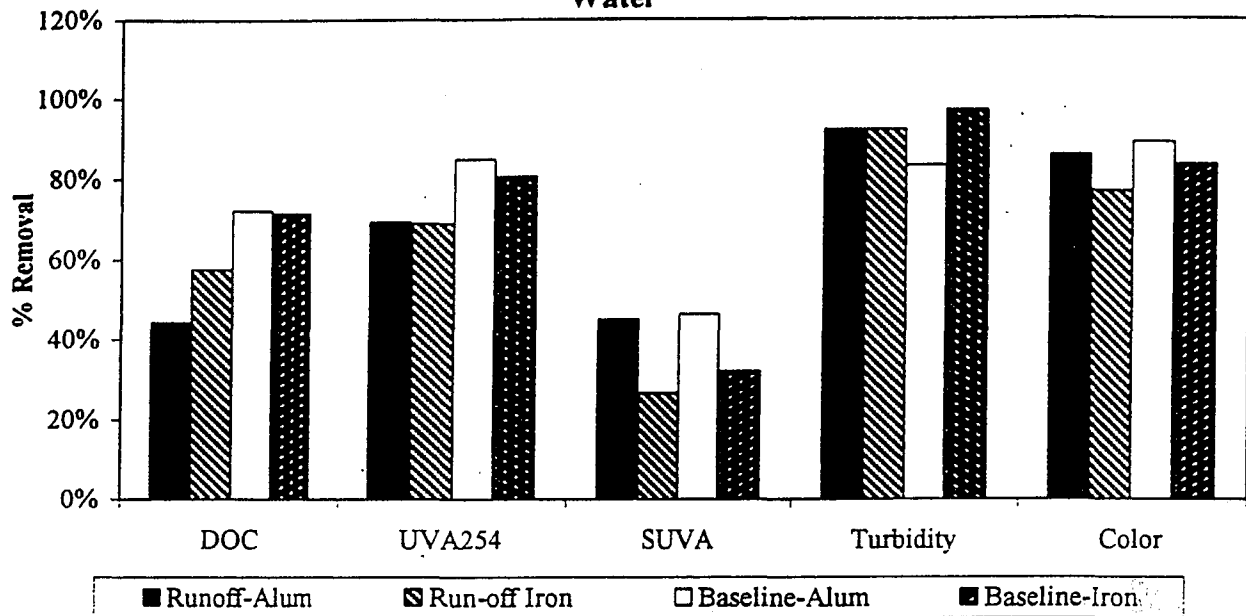
Figure-5-34: Twitchell, Percent Removal in Raw vs Optimized Treated Water

Figure 5-35: Flux Decline of YM3, GM, PM10 with Twitchell
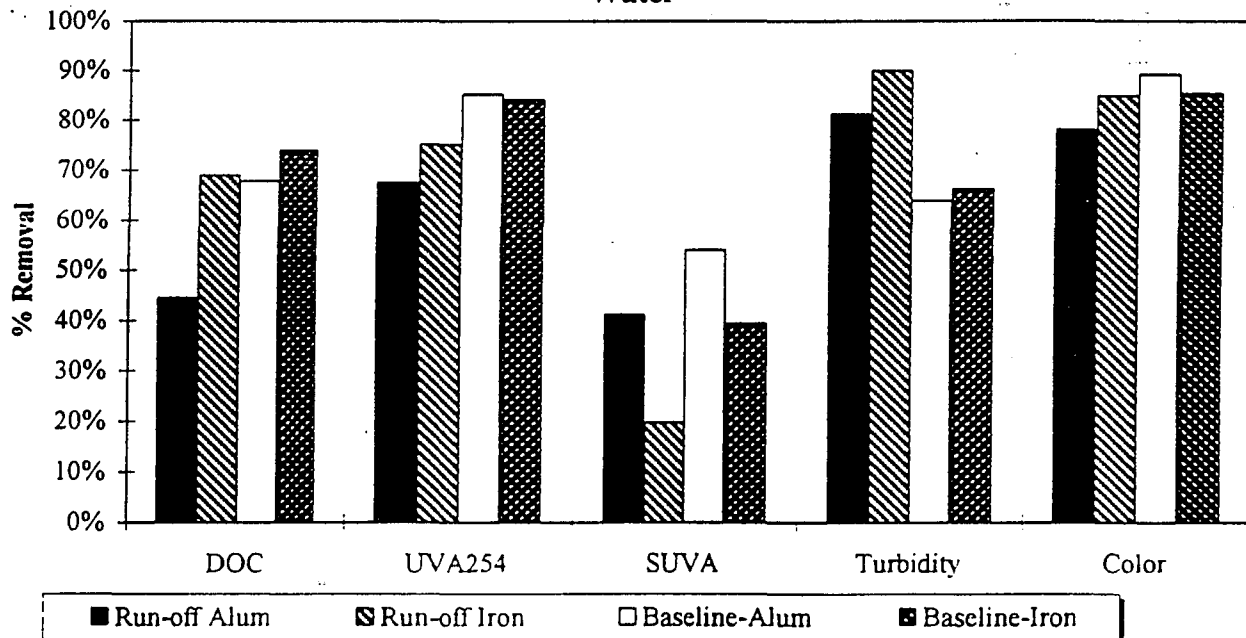
Figure 5-35: Flux Decline of YM3, GM, PM10 with Twitchell

Figure 5-36: NF45 with Twitchell Water (initial values: pH 7.05, DOC 47.8 mg/L, UVA 1.76 cm^{-1})
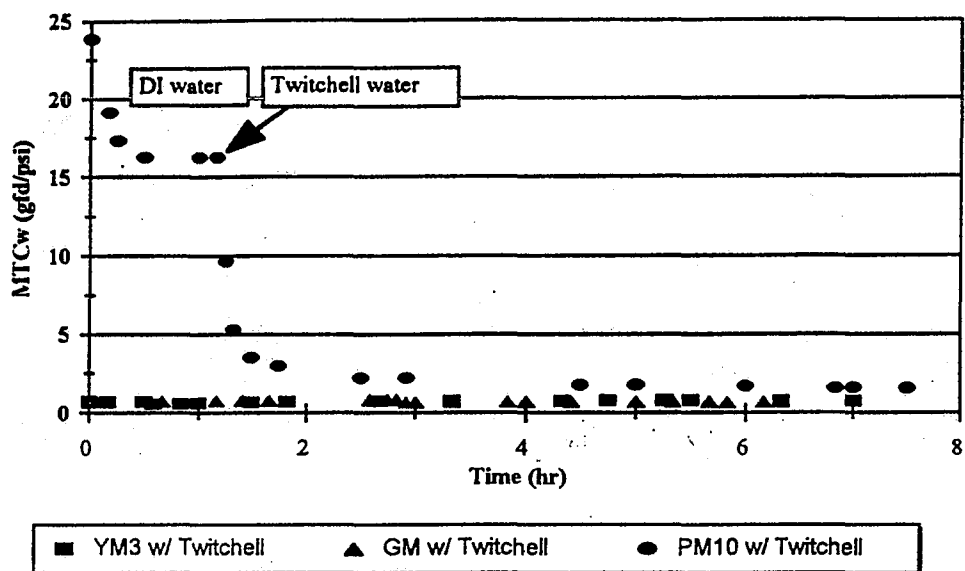
Figure 5-36: NF45 with Twitchell Water (initial values: pH 7.05, DOC 47.8 mg/L, UVA 1.76 cm^{-1})
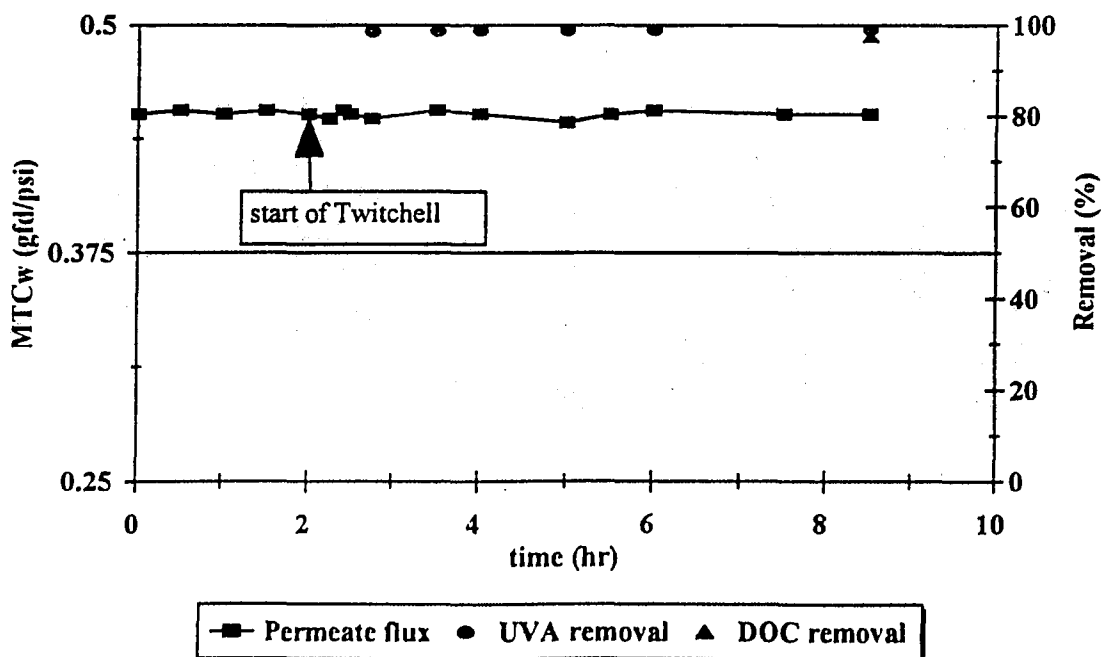
Figure 5-37: GM Membrane with Twitchell Water (Initial values: pH 7.05, DOC 37.38 mg/L, UVA 1.801 cm⁻¹)
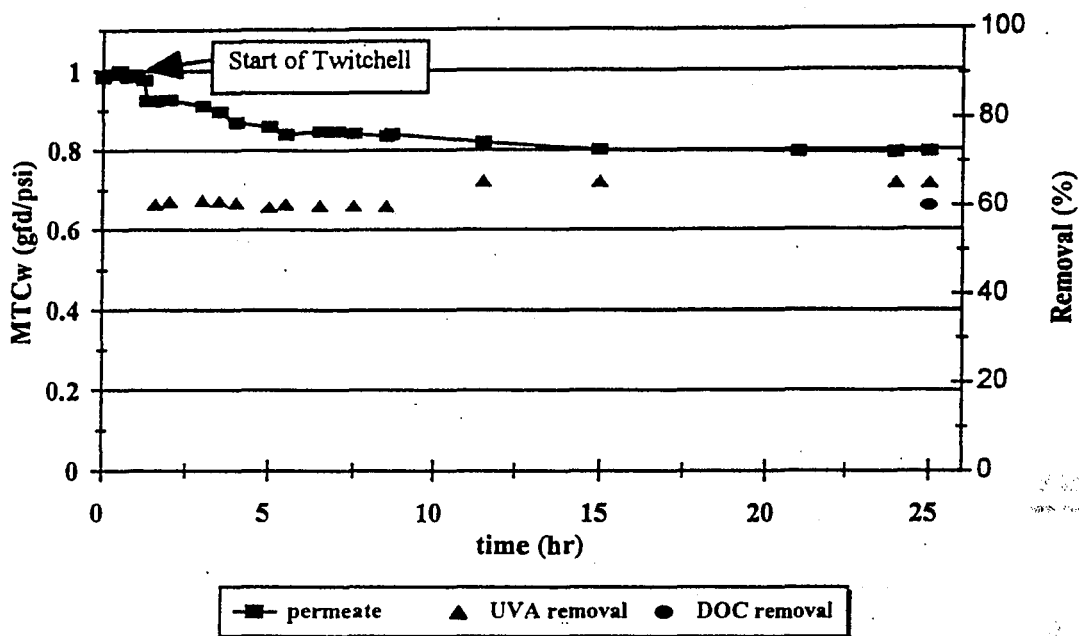
Figure 5-38: GM andTwitchell + Ca 4mM (pH 7.05, DOC 41.76 mg/L, UVA 1.801 cm⁻¹)
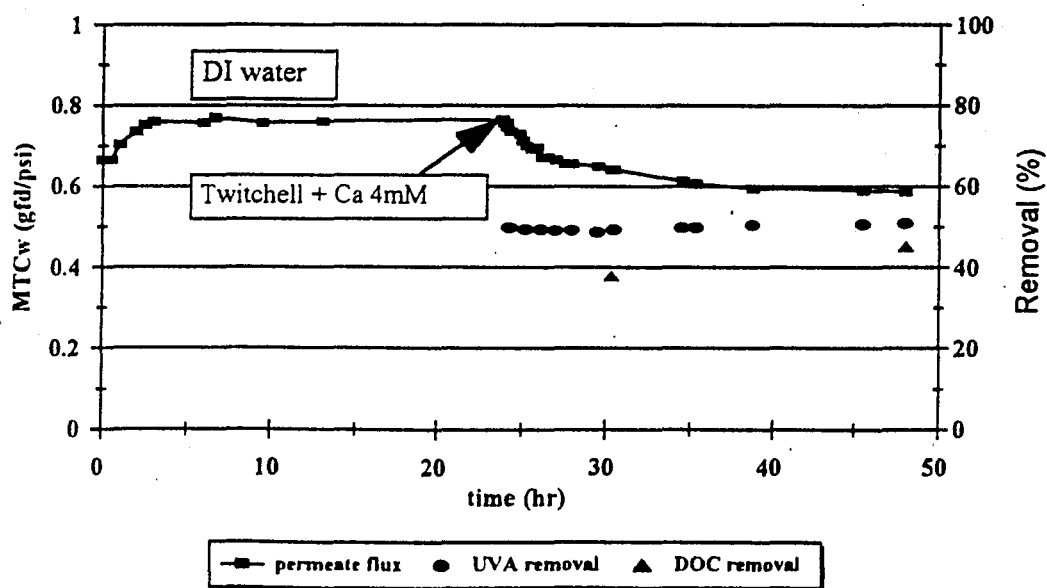
Figure 5-39: Flux Curve of NF45 Membrane and Iron Supernatant Water
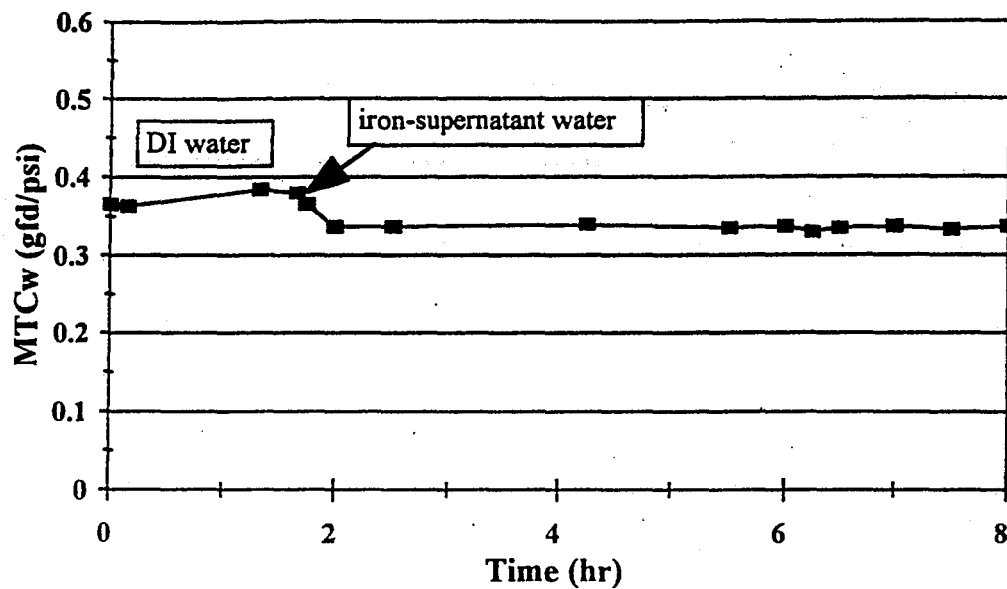
Figure 5-40: Flux Curve of GM and Iron-Supernatant Water
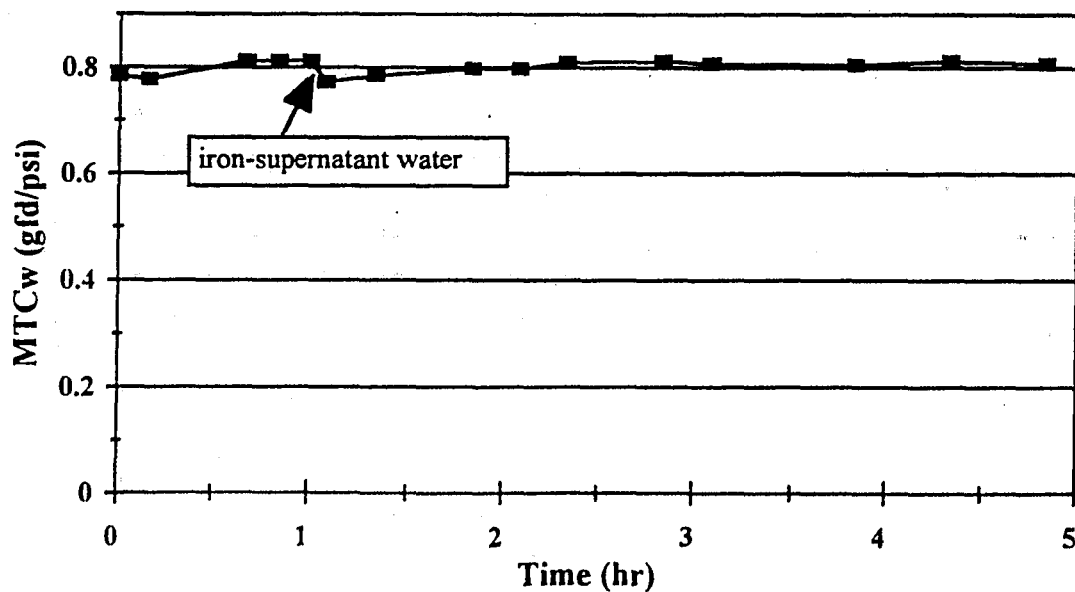
Figure 5-41: Water Quality of Twitchell (Initial values; Color 244, NH₃-N= 5.06 mg/L, Fluorescence 105, SUVA = 0.037)
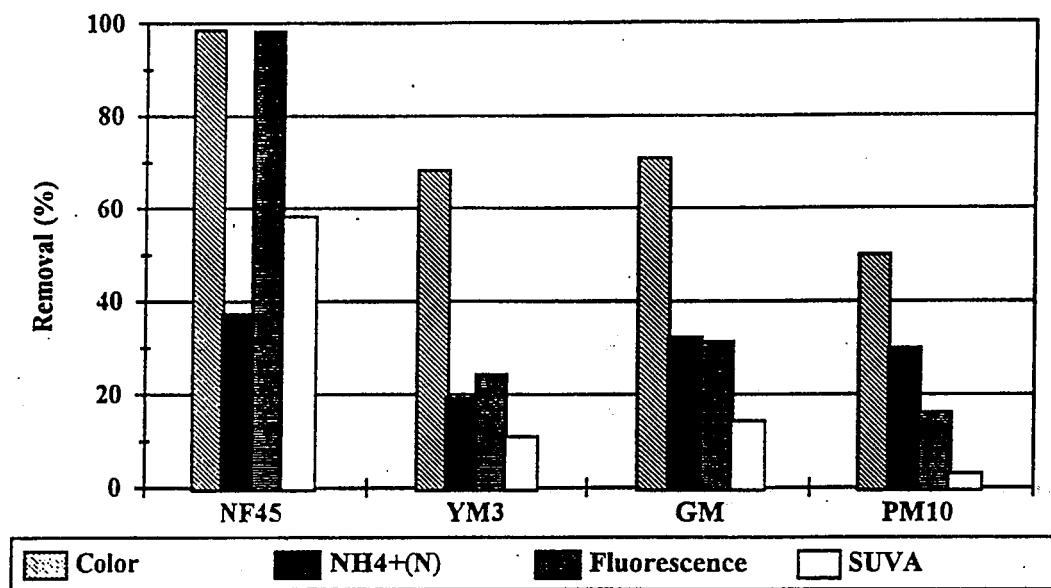
Figure 5-42: NOM Rejections with Twitchell (Initial values: DOC 47.8 mg/L, SUVA 0.037, THMFP 2227 ug/L)
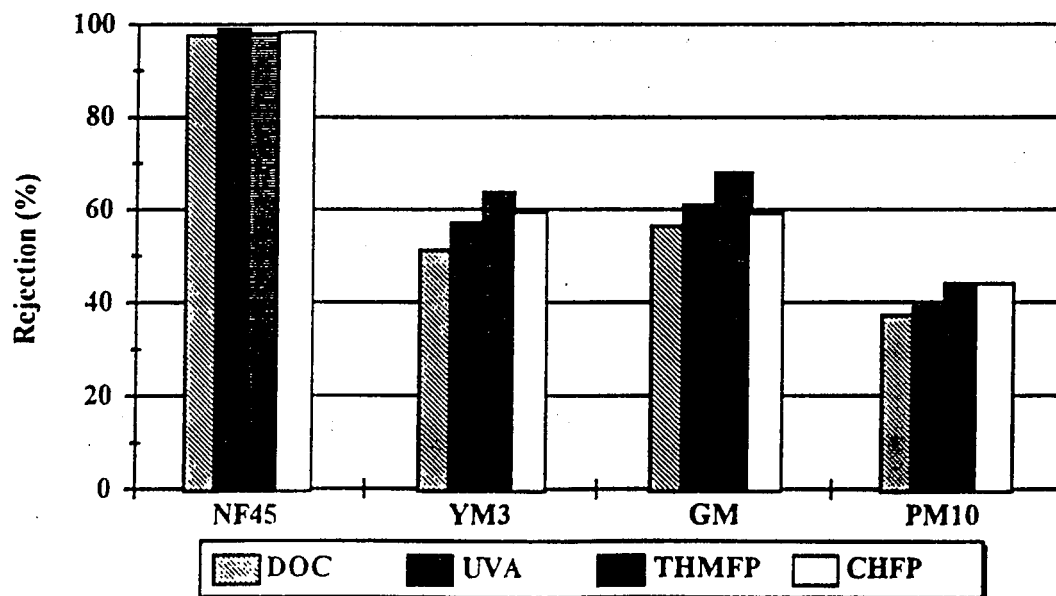
**Figure 5-43: NOM Removal of Twitchell Water Using GM Membrane
(Initial values: pH 7.04, DOC 38.44 mg/L, UVA 1.816 1/cm, Color 262)**
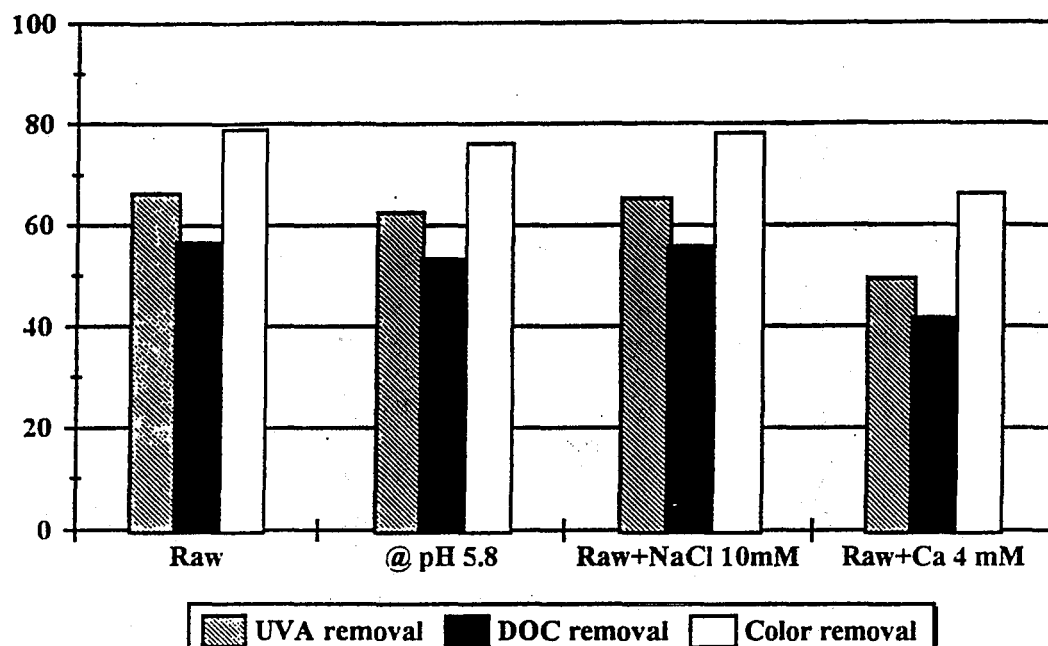
Figure 5-44: MWD by HPSEC: Raw versus Membrane Permeate

Overall Removal of GM
membrane = 56.3 %
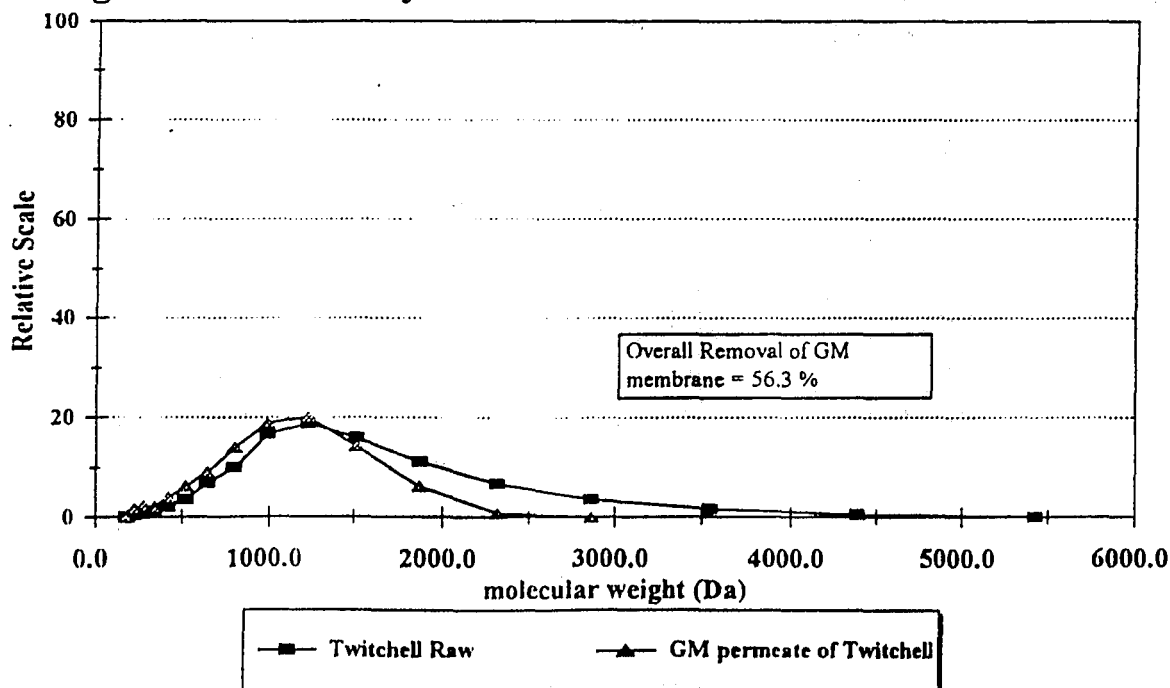
Figure 5-45: NOM Rejection of Supernatant Water (Initial values: DOC 12.4 mg/L, UVA 0.356 cm^{-1})
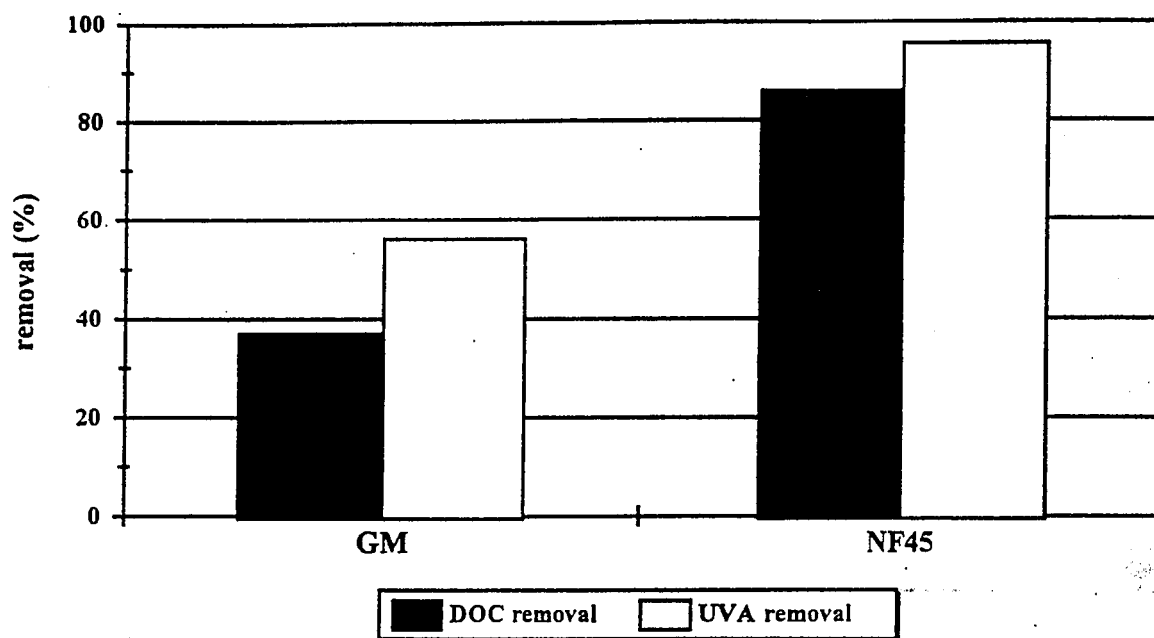
Figure 5-46: MWD of Twitchell Water by HPSEC
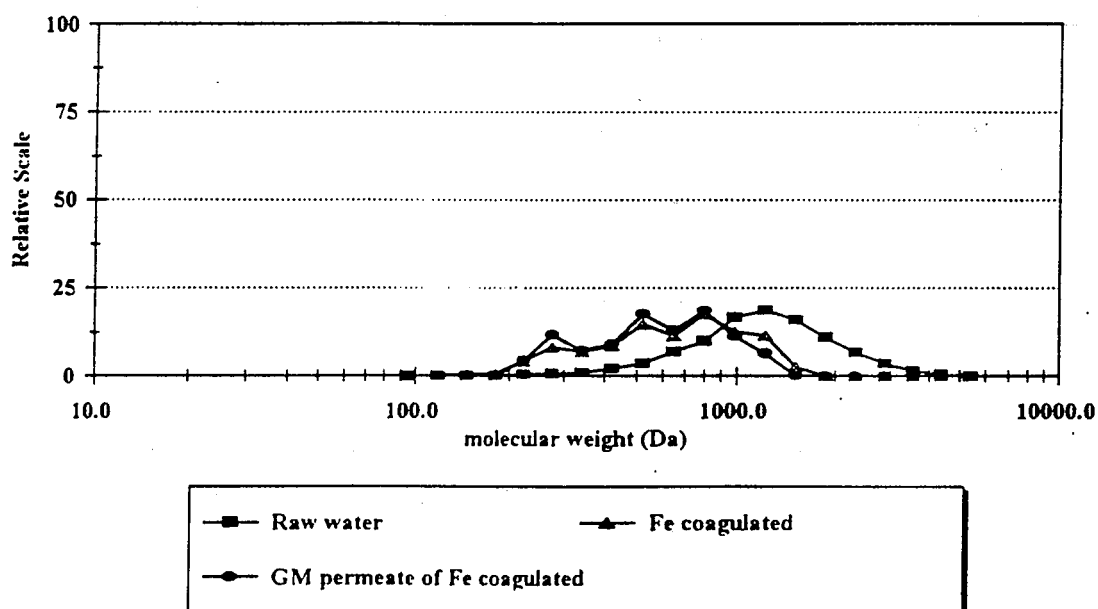
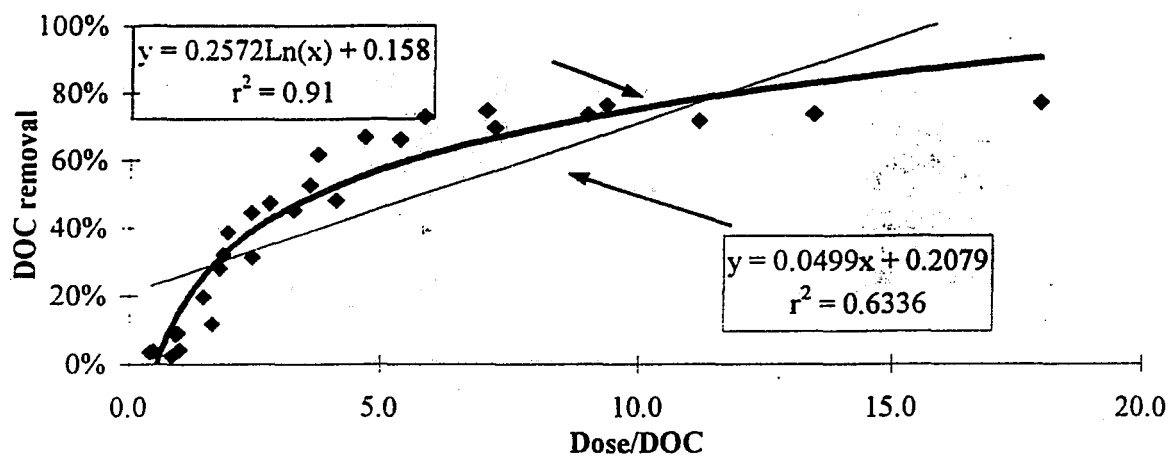Figure 5-47: Correlation of Dose/DOC vs. DOC Removal by Alum Optimized Coagulation for Delta waters

$y = 0.2572Ln(x) + 0.158$
$r^2 = 0.91$

$y = 0.0499x + 0.2079$
$r^2 = 0.6336$

Figure 5-48: Correlation of Dose/DOC vs. DOC Removal by Iron Optimized Coagulation for Delta waters

$y = 0.2125Ln(x) + 0.3096$
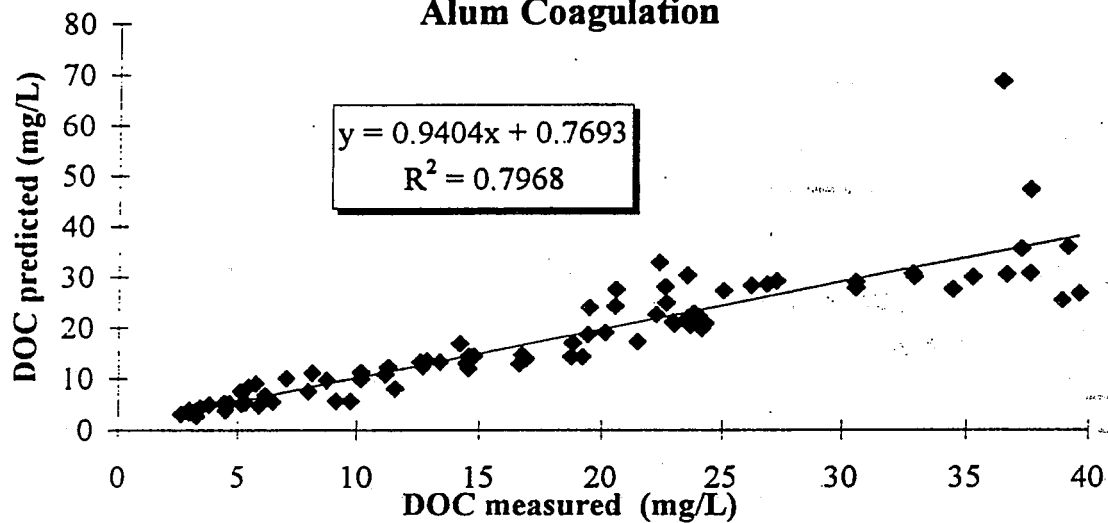$R^2 = 0.8319$

$y = 0.0462x + 0.2802$
$R^2 = 0.5594$
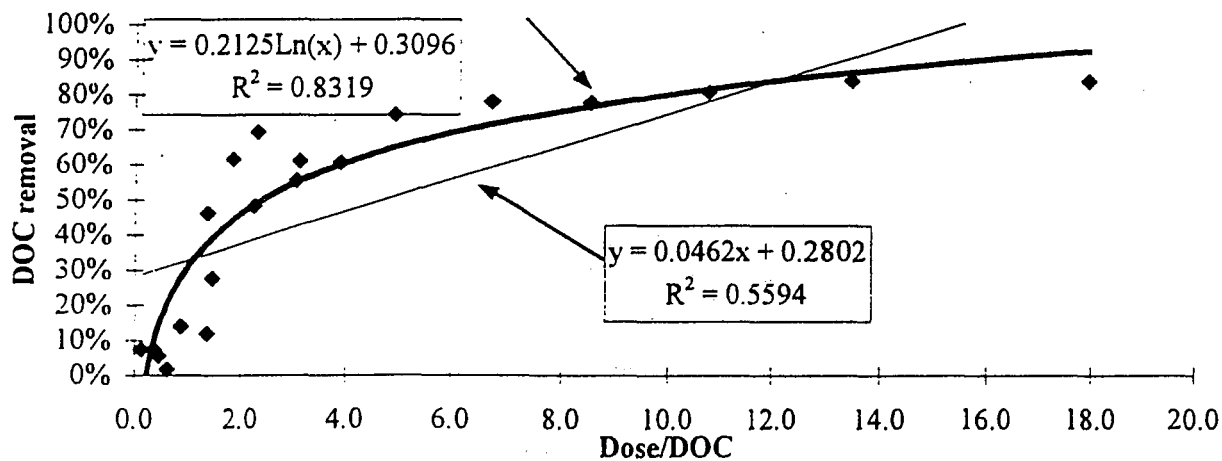
Figure-5-49: Internal Validation of DOC model for Alum Coagulation

$$y = 0.9404x + 0.7693$$
$$R^2 = 0.7968$$
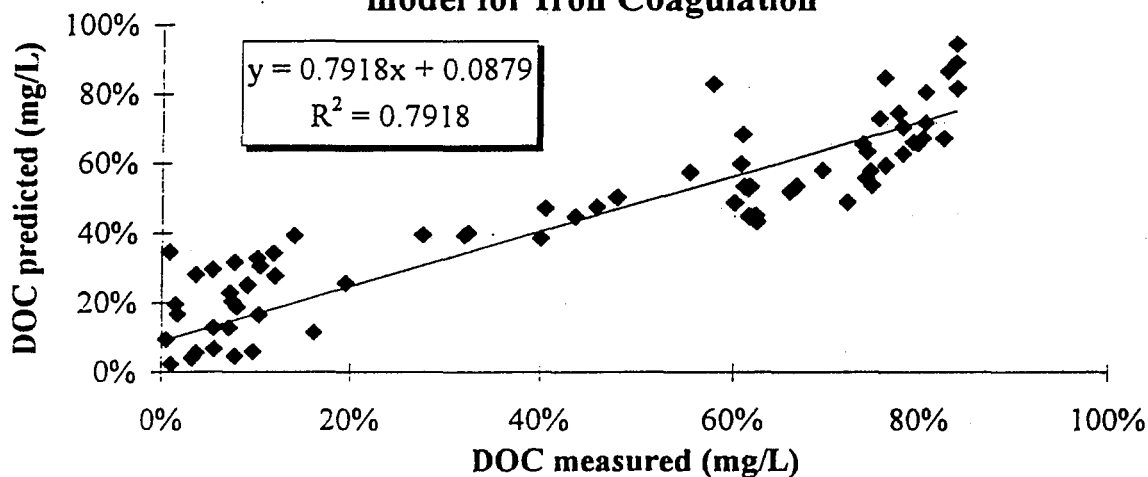

Figure-5-50: Internal Validation of DOC model for Iron Coagulation

$$y = 1.0187x - 0.3159$$
$$R^2 = 0.7351$$
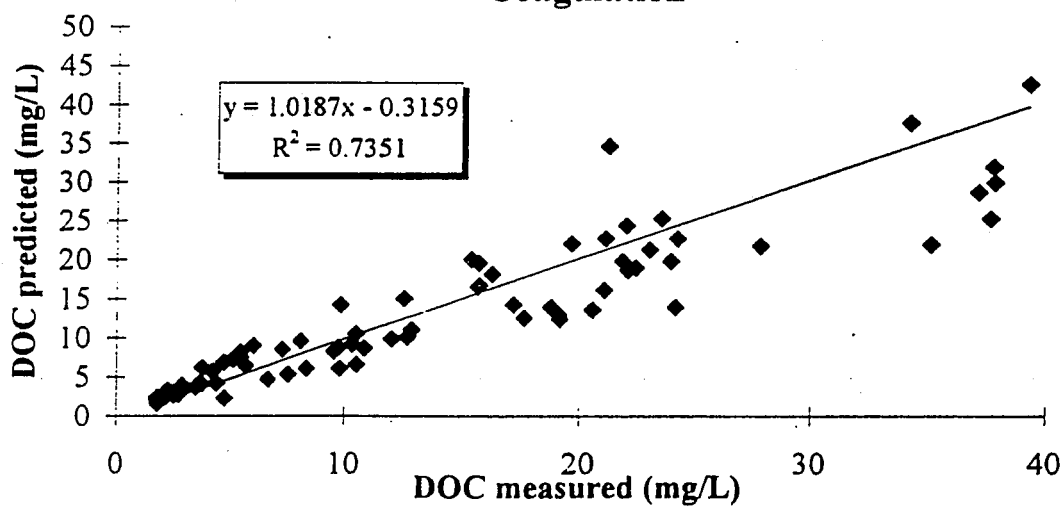
Figure-5-51: Internal Validation of % DOC Removal model for Alum Coagulation

Scatter plot with axis "DOC predicted (mg/L)" (y-axis, 0% to 100%) versus "DOC measured (mg/L)" (x-axis, 0% to 100%).

$$y = 0.7561x + 0.0779$$
$$R^2 = 0.7567$$
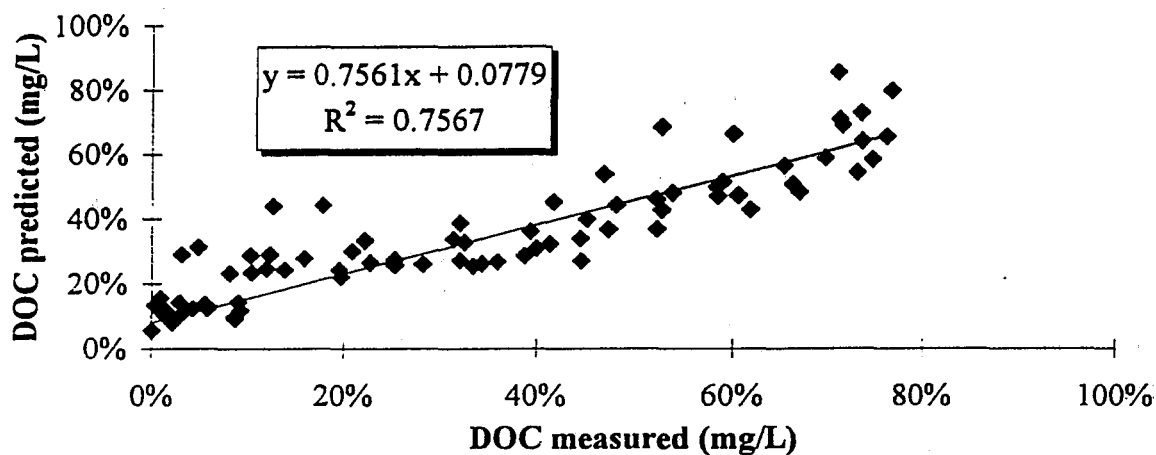
Figure-5-52: Internal Validation of % DOC Removal model for Iron Coagulation

Scatter plot with axis "DOC predicted (mg/L)" (y-axis, 0% to 100%) versus "DOC measured (mg/L)" (x-axis, 0% to 100%).

$$y = 0.7918x + 0.0879$$
$$R^2 = 0.7918$$

Figure 5-53: Sensitivity Analysis of DOC model for Alum Coagulation
(Initial DOC = 20 mg/L)
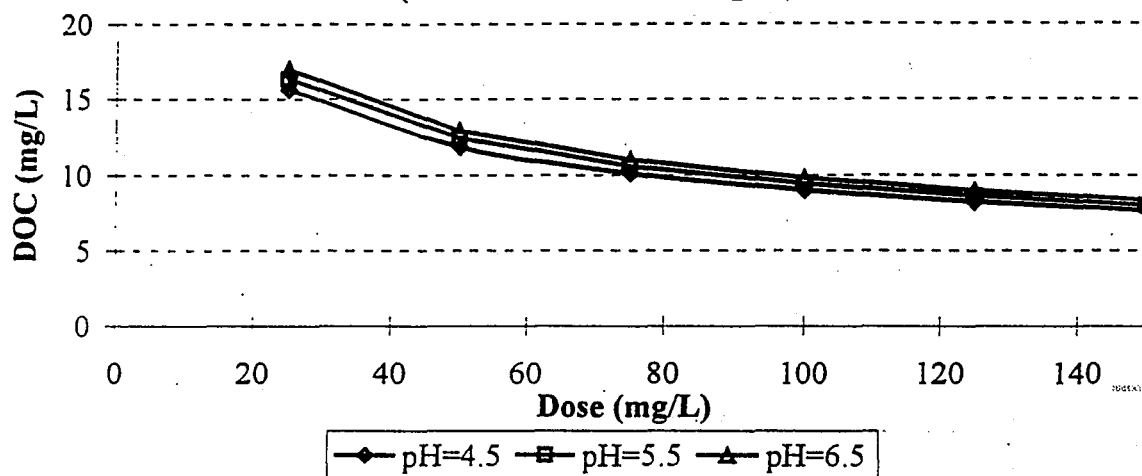
Figure 5-54: Sensitivity Analysis of DOC model for Iron Coagulation
(Initial DOC = 20 mg/L)